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INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS

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Alternatives For Reducing Oil Imports

3952-39

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INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS

Alternatives For Reducing Oil Imports

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Foreword

This report presents the findings of an assessment requested by the Senate Committee on Commerce, Science, and Transportation. The study assesses and compares increased automobile fuel efficiency and synthetic fuels production with respect to their potential to reduce conventional oil consumption, and their costs and impacts. Conservation and fuel switching as a means of reducing stationary oil uses are also considered, but in considerably less detail, in order to enable estimates of plausible future oil imports.

We are grateful for the assistance of the project advisory panels and the many other people who provided advice, information, and reviews. It should be understood, however, that OTA assumes full responsibility for this report, which does not necessarily represent the views of individual members of the advisory panels.

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Chapter 1

Executive Summary

INTRODUCTION

In 1981, U.S. oil imports averaged 5.4 million barrels per day (MMB/D)—approximately 34 percent of its oil consumption and 15 percent of its total energy use. This is potentially a serious risk to the economy and security of the United States. Furthermore, recovery from the current recession will increase demand for oil and, although currently stable, domestic oil production is likely to resume a steady decline in the near future.

Several options exist for reducing oil imports. However, even with moderate increases in automobile fuel efficiency, moderate success at developing a synthetic fuels industry and the expected reduction in stationary use of fuel oil, U.S. oil imports could still be over 4 MMB/D by 2000, if the U.S. economy is healthy and has not undergone unforeseen structural changes that might reduce oil demand well below projected levels.

Only with vigorous promotion of all three options and technological success can the Nation hope to eliminate oil imports before 2010.

Congress faces several decisions on how to reduce the U.S. dependence on imported petroleum. Two options, increased automobile efficiency and synthetic fuels, are particularly likely to be subjects of congressional debates. First, Congress may want to consider new incentives to increase auto fuel efficiency beyond that mandated by the 1985 CAFE (Corporate Average Fuel Efficiency) standards. Second, Congress will have to decide whether to continue into the second phase of the program to accelerate synfuels development under the Synthetic Fuel Corp. (SFC). The purpose of this report is to assist Congress in making these decisions and comparing these options by exploring in detail the major public and private costs and benefits of increased automobile fuel efficiency and synthetic fuels production. A third option for reducing imports—increased efficiency and fuel switching in stationary (nontransportation) oil uses—is examined briefly to allow an assessment of potential future levels of oil imports. Finally, electric-powered automobiles are examined.

CONCLUSIONS AND COMPARISONS

Import Reductions

In the judgment of the Office of Technology Assessment, increased automobile fuel efficiency, synthetic fuels production, and reduced stationary (nontransportation) use of oil can significantly decrease U.S. dependence on oil imports during the next two to three decades. Indeed, reducing oil imports as quickly as possible requires that all three options be pursued. Electric cars are unlikely to play a significant role, however.

Although a precise forecast of the future contributions of the import reduction options is not feasible now, it is possible to draw some general conclusions about their likely importance and to estimate what their contributions **could be** under specific circumstances (see fig. 1).

First, **increases in auto fuel efficiency will continue, driven by market demand and foreign competition.** OTA believes that, with strong and consistent demand for high fuel efficiency, there is a good chance that actual average new-car fuel efficiencies would be greater than OTA's low scenario in which average new-car fuel economy* was projected to be:

30 miles per gallon (mpg)	in 1985
38 mpg	in 1990
43 mpg	in 1995
51 mpg	in 2000

with a moderate shift in demand to smaller cars. Although this scenario is based on modest technical expectations, it is dependent on favorable market conditions. Domestic automakers are unlikely to commit the capital necessary to continue

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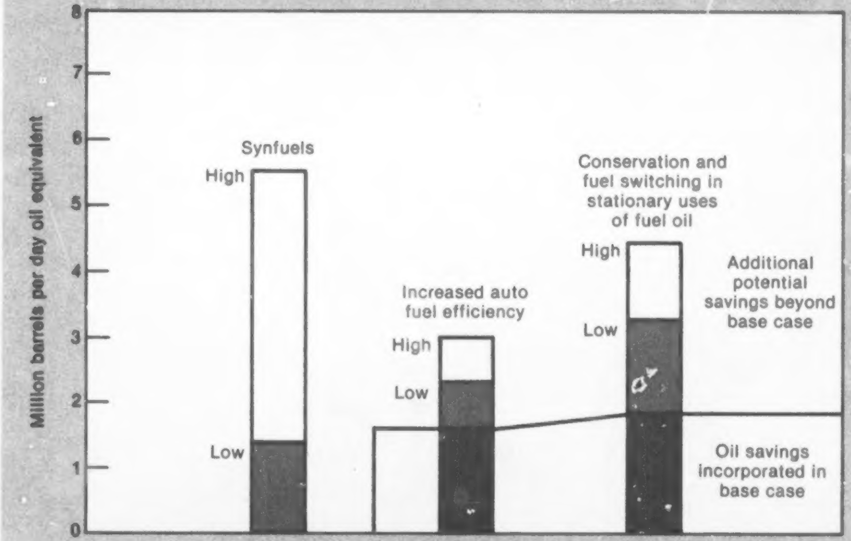
*EPA values, based on 55 percent city, 45 percent highway. On-the-road fuel economy is expected to average about 10 percent less.

Figure 1.—Potential Oil Savings Possible by the Year 2000[a] (relative to 1980 demand)



[a] These potential oil savings (or synfuels production) are for the year 2000. Their costs as well as a description of the technologies and other characteristics of the high and low scenarios are given in this summary.

SOURCE: Office of Technology Assessment.

the current rapid rate of increase in efficiency unless they improve their sales and profits.

If the industry is able to attain the fuel efficiency levels shown above, the United States would save 800,000 barrels per day (bbl/d) of oil by 2000 compared with the case where post-1985 new-car efficiency remained at 30 mpg. The savings would increase to at least 1.1 MMB/D by 2010 because of continued replacement of older, less fuel-efficient automobiles.

With a poorer economic picture and weaker demand for high fuel efficiency, new-car efficiencies could be 40 mpg or less by 2000, with correspondingly lower savings. Achieving 60 to 80 mpg by 2000 would require not only favorable economic conditions and strong demand for fuel efficiency, but also relatively successful technical development.

Second, **substantial contributions to oil import reductions from production of synthetic fuels appear to be less certain than substantial contributions from the other options.** Potential synfuels producers are likely to proceed cautiously for the following reasons: 1) investment costs are very high (even with loan guarantees covering 75 percent of project costs); 2) there is a fairly small differential between the most optimistic of OTA's projected synfuels production costs and the current price of oil; 3) investors are now uncertain about future increases in the real price of oil; and 4) there are high technological risks with the first round of synfuels plants (possibly exacerbated by the cancellation of the Department of Energy's (DOE) demonstration program).

OTA projects that, even under favorable circumstances, fossil-based production of synthetic *transportation fuels* could at best be 0.3 to 0.7 MMB/D by 1990 and 1 to 5 MMB/D by 2000. Biomass synfuels could add 0.1 to 1 MMB/D to this total by 2000. In less favorable conditions—for example, if the SFC financial incentives were withdrawn—it appears unlikely that even the lower fossil synfuels estimate for 1990, and perhaps 2000, could be achieved unless oil prices increase much faster than they are currently expected to.

Achieving much more than 1 MMB/D of synfuels production by 2000 would require fortuitous technical success and either: 1) unambiguous economic profitability or 2) continued financial incentives requiring authorizations considerably larger than those currently assigned to SFC. Achieving production levels near the upper limits for 2000 are likely to be delayed, perhaps by as much as a decade, unless there is virtually a "war mobilization"-type effort.

Third, **there are likely to be large reductions in the stationary use of fuel oil (currently 4.4 MMB/D) in the next few decades.** With just cost-effective conservation measures, stationary fuel oil use could be reduced significantly. Additional conservation measures by users of electricity and natural gas could make enough of these fuels available to replace the remaining stationary fuel oil use by 2000. Total elimination of stationary fuel oil use by 2000 is unlikely, however, because site-specific factors and differing investor payback requirements will mean that a significant fraction of the numerous investments needed for elimination will not be made.

Fourth, **even a 20-percent electrification of the auto fleet—a market penetration that must be considered improbable within the next several decades—is unlikely to save more than about 0.2 MMB/D.** Electric cars are most likely to replace small, low-powered—and thus fuel-efficient—conventional automobiles, minimizing potential oil savings.

Plausible projections of domestic oil production—expected by OTA to drop from 10.2 MMB/D in 1980 to 7 MMB/D or lower by 2000—suggest that oil imports could still be as high as 4 to 5 MMB/D or more by 2000 unless imports are reduced by a stagnant U.S. economy or by a resumption of rapidly rising oil prices.* Achieving low levels of imports—to perhaps less than 2 MMB/D within 20 to 25 years—is likely to require a degree of success in the three major options that is greater than can be expected as a result of current policies.

Costs

Except for stationary fuel oil reductions, economic analysis of the options for reducing oil imports involves a comparison of **tentative** cost estimates for mostly **unproven** technologies that will **not be deployed for 5 to 10 years or more.** Even if costs were perfectly estimated for today's market (and the estimates are far from perfect), different rates of inflation in the different economic sectors affecting the options could dramatically shift the comparative costs by the time technologies are actually deployed. Figure 2 presents OTA's estimates for the investment costs for all options except electric cars. The costs are expressed in dollars per barrel per day, which is the amount of investment needed to reduce petroleum use at a rate of 1 bbl/d.* In OTA's judgment, **the estimated investment costs (in dollars per barrel per day) during the 1990's of automobile efficiency increases, synthetic fuels production, and reduction of stationary uses of oil are essentially the same, within reasonable error bounds. If Congress wishes to channel national investments preferentially into one of these options, differentials in estimated investment costs cannot provide a compelling basis for choice.**

On the other hand, **investments during the 1980's to reduce stationary oil use** (from the current 4.4 to 3 MMB/D or less by 1990) **and increase automobile fuel efficiency** (to a 35 to 45 mpg new-car fleet average by 1990) **are likely to cost less than the 1990-2000 investments in any of the options.**

Electric vehicles are likely to be very expensive to the consumer—costing perhaps $3,000 more per vehicle than similar, conventional automobiles or $300,000 to $400,000/bbl/d of oil saved. (The latter is not strictly comparable to investment costs for the other options.) If batteries must be replaced at moderate intervals, which is necessary today, the total costs of electric cars would escalate.

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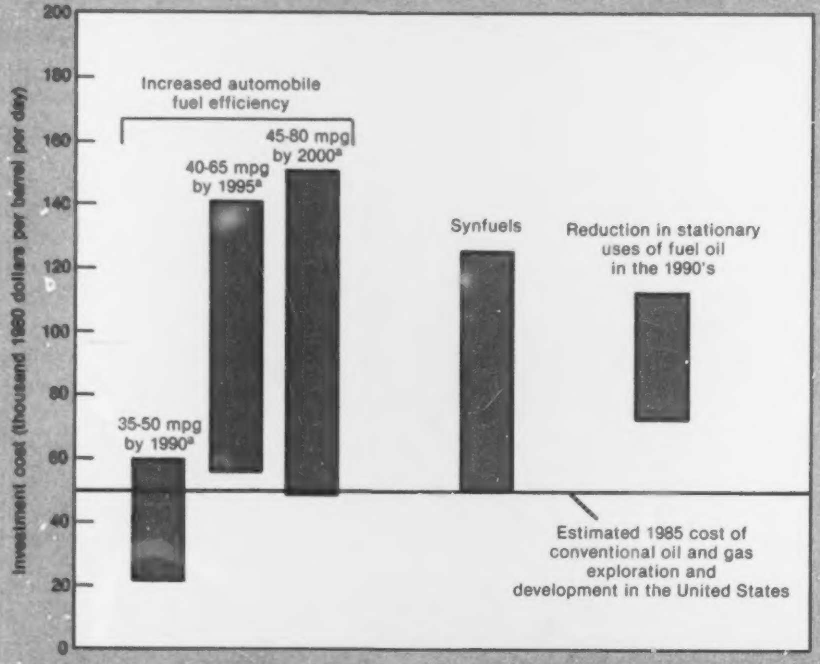
*Rapidly rising oil prices are unlikely to occur simultaneously with a stagnant U.S. economy unless the economies (and oil import requirements) of Europe and others are thriving at the same time.

*This measure was chosen in order to avoid problems that arise when comparing investments in projects with different lifetimes and for which future oil savings may be discounted at different rates.

Figure 2.—Estimated Investment Costs for the Oil Import Reduction Options



[a] Average new-car fuel efficiency (55%/45% city/highway EPA fuel efficiencies). Fuel savings calculated by comparing fuel efficiency of cars produced at end of each 5-year period to the average new-car fuel efficiency of cars produced at end of previous 5-year period.

SOURCE: Office of Technology Assessment.

Technological and Economic Risks

The general perception of the technological and economic risks of the import reduction options is: 1) that the reduction of stationary oil use has comparatively predictable costs and few technological risks; 2) that synthetic fuels have severe economic and technological risks; and 3) that increased auto fuel efficiency has moderate economic and technological risks. OTA's analysis indicates that these perceptions are correct only to a limited extent.

- Although the costs and technology of fuel switching are well known and involve little risk, the success of retrofitting a given building to increase its energy efficiency often cannot be accurately predicted because of site-specific considerations that cannot be adequately quantified.
- The differences in risks between synfuels development and increased automobile fuel efficiency are less a matter of overall magnitude than of timing.
- Synfuel production involves considerable technical and economic risks for the first round of commercial-scale facilities, but once full-scale process units have been demonstrated the risk for future plants should drop substantially.
- Some increases in automobile fuel efficiency can be implemented with negligible technological and small economic risks, but increases to very high efficiencies do involve significant

technical and economic risks. Also, as the number and rate of changes in automobiles increases, there is increased risk that consumers will not accept the automobiles and that insufficient development and testing will lead to poor on-the-road performance and/or product recalls.

Additional Bases for Comparison—Environmental, Social, and Economic Effects

Increased auto fuel efficiency may reduce vehicle safety as cars are made smaller and lighter. But in all but extreme cases of vehicle size reduction, improvements in vehicle design and increased passenger use of safety restraints have the potential to offset any effects of reduced size and weight on the vehicle's protection of its occupants in a crash.

Continued pressure for increased fuel efficiency will dictate new plant investments which will reinforce the ongoing restructuring of the U.S. auto industry. This restructuring involves a shift in manufacturing away from the traditional production centers to the Sun Belt and overseas, and stronger industry ties with foreign manufacturers. The composition and size of the manufacturing work force may evolve towards a greater proportion of skilled workers but fewer workers overall. Increased sophistication and capital investment may be required for vehicle maintenance. A reduction in the number of suppliers to the auto industry may also result.

Large-scale synthetic fuels production would generate significant amounts of toxic substances, posing risks of health damage to workers and possible risks to the public through contamination of ground waters or by small amounts of toxics left in the fuels. There should not be any technological barrier to adequate control of these substances, but OTA concludes that there are substantial reasons to be concerned about the adequacy both of proposed environmental protection systems and of the existing regulatory structure.

Other important effects of synfuels production stem from the very large scale of both the individual projects and, potentially, the industry as a whole. These may overwhelm the social and economic resources of nearby population centers, especially in sparsely populated areas of the West. At national production levels of a few million barrels per day, impacts from coal and shale mining and population pressures on wilderness areas and other fragile ecosystems can be substantial even in comparison with major industries such as coal-fired power generation. On the other hand, conventional air pollution problems from such plants are likely to be considerably less than those associated with similar amounts* of coal-fired power generation.

Finally, although water requirements for synfuels are a small fraction of total national consumption, **growth of a synfuels industry could either create or intensify competition for water, depending on both regional and local factors.** Such competition is of special concern in the arid West. Unfortunately, a reliable determination of both the cumulative impacts on other water users and, in some instances, the actual availability of water for synfuels development is precluded by physical and institutional uncertainties, changing public attitudes towards water use priorities, and the analytical shortcomings of existing studies.

However, in areas where there are relatively few obstacles to transferring water rights (e.g., as is currently the case in Colorado), developers should be able to obtain the water they need because their consumption per barrel of oil produced is small enough to enable them to pay a relatively high price without significantly affecting the final cost of their products.

Electric vehicles, if they are ever produced in large quantities, could have an important positive environmental effect—the reduction of automobile exhaust emissions and resulting improvements in urban air quality.

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*On a "per unit of coal used" basis.

POLICY

OTA's analysis points to two conclusions that may warrant congressional consideration of changes in current Federal energy policy.

First, current policies affecting investments in energy conservation and domestic energy production are not likely to result in levels of oil imports below 4 MMB/D in 2000, if the U.S. economy is healthy and has not undergone unforeseen structural changes that might reduce oil demand well below projected levels. During the next 20 years, OTA expects that, under these policies, oil import reductions due to synthetic fuels production and decreased stationary and automobile oil use will be partially offset by a decrease in domestic production of conventional oil. Reducing net oil imports to 1 or 2 MMB/D or less by 2000 is likely to require more vigorous pursuit of all options for reducing domestic consumption of conventional oil products. On the other hand, elimination of current conservation and synthetic fuels production policies could cause imports to range from 5 to 6 MMB/D by 2000 under these same economic conditions.

Second, current policies may not provide society with adequate protection from some of the adverse side effects of synthetic fuels development and increased automobile fuel efficiency. Of particular concern are possible reductions in automobile crash safety (as the number of smaller, more fuel-efficient cars increases), inadequate control of toxic substances from synfuels development, and adverse socioeconomic effects from both options.

Because of the large technical, economic, and market uncertainties inherent in the analyses of oil displacement options, Congress may wish to emphasize flexible incentives with provisions for periodic review and adjustment. A stable commitment to oil import displacement will be necessary, however, to maximize the effect of such policies.

Stimulating Oil Import Reductions

The level of oil imports at the turn of the century will be determined by market forces, modified by Government policy towards oil supply and demand. The imposition of Federal policy on the workings of the private market generally is justified on the basis of the market's failure to value public costs and benefits. A particularly important public cost of U.S. dependence on imported oil, for example, is the national security problem imposed by political instability in the Middle East and the resulting potential for oil cutoffs. Although the precise magnitude of these costs is debatable, most people would agree that they are significant ($5 to $50/bbl depending on various circumstances) and that the private market generally does not take them into account.

Efforts to displace imports also have both public and private costs. In addition to the potential side effects just mentioned, Government interference in the oil marketplace can cause significant misallocations of resources. Congress will have to balance costs and benefits, which cannot be reduced to common measures and which change with time, in a complex tradeoff.

One policy option to displace imports is an energy tax, either on oil imports or on oil in general. Both taxes have the advantage of encouraging alternatives to conventional oil consumption without predetermining which adjustments would be made. They could be used to provide consistent price signals to the market—to assure the auto industry, for example, that demand for fuel-efficient cars would continue and to assure synfuels developers that they would receive at least a constant real price for their products. Imposing a tax only on transportation fuels would send the same signal to both the auto industry and to producers of synthetic transportation fuels, but this preferential treatment would be at the expense of other conservation or synfuels production investors.

All of these petroleum taxes also have a number of other effects which must be considered. For example, a tax only on oil imports leads to an income transfer from domestic oil consumers to domestic oil producers; and all oil taxes can lead to reduced international competitiveness of domestic industries heavily dependent on oil, such as the petrochemical industry.

Policies can also be directed specifically at the automobile or synfuels industries. The most effective of these options will be those that directly address the factors that shape, direct, and limit the contributions that the automobile and synfuels industries can make to import displacement.

The critical factors that determine the pace of **increased automobile fuel efficiency** are consumer demand for fuel efficiency and the financial health of the domestic auto industry. If the industry is uncertain about demand, it will be reluctant to make the expensive investments. And with continued poor sales, the industry will be less able to afford them.

Aside from energy taxes, Congress can maintain and stimulate consumer demand for fuel efficiency by a variety of measures that would raise the relative costs to consumers of owning inefficient cars. For example, registration fees (one time or annual) and purchase taxes or subsidies are incentives that can be directly linked to fuel efficiency. However, fuel-efficiency incentives that do not discriminate with respect to car size would tend to increase sales of small cars at the expense of larger cars. Such discrimination might hurt domestic manufacturers, which have been most vulnerable to foreign competition in the small-car market.

Congress can also choose policies aimed at auto production such as continuing to require manufacturers to improve fuel efficiency by means of stricter CAFE or similar standards that would ensure increased fuel efficiency even if demand for this automobile attribute is low. This regulatory route might reduce some risks to automakers by requiring all to make similar investments. On the other hand, car sales may suffer if the costs of the fuel savings—either in higher sticker prices or reductions in some desirable vehicle attributes—are higher than consumers are willing to pay. Fuel-economy requirements are likely to be perceived by the industry as exceedingly risky unless the requirements are accompanied by measures to stimulate demand or to ease the resulting financial burden on the automakers.

To help ensure that the fuel-efficient cars are actually bought and that the automakers can acquire the capital needed for increasing fuel efficiency, Congress may also wish to directly promote sales of fuel-efficient cars. A low-interest-rate loan program (with interest rates tied to fuel efficiency) is one potentially effective mechanism. Congress may also wish to consider awarding direct grants or loan guarantees for qualifying investments in auto manufacturing facilities.

The factors that determine the pace of **synfuels development** are the high degree of technical uncertainty and the continuing uncertainty about future oil prices. Both areas of uncertainty contribute to doubts about profits.

Current Federal policy maintains the valuable incentives associated with SFC, but deemphasizes DOE's research, development, and demonstration programs. The loan guarantee mechanism offered by SFC significantly improves the probability of financial success for a developer and probably will be necessary to ensure even a few hundred thousand barrels per day of synfuels production by the early 1990's. Several major risks to synfuels investors remain, however. Cost overruns could nullify any potential profits because developers must base their product prices on the market prices of competing fuels rather than on synfuels production costs. It is also probable that several first generation commercial-scale units will function poorly, and rapid expansion of the industry may thereby be delayed.

Since the SFC program appears to be attracting the capital needed to build and demonstrate a series of first generation commercial-scale production units, cancellation of DOE's programs may not turn out to be particularly harmful to synfuels development **if the first plants perform well.** However, cancellation of the demonstration program probably will mean that fewer technologies reach the stage where SFC support is possible. Deemphasis of development programs may also delay findings that would be useful in fixing the technical problems that are likely to arise in the first commercial-scale units. To hedge against the possibility of poor operation delaying expansion, Congress may wish to support development programs intended to demonstrate the technical feasibility of a variety of processes and to gain basic knowledge of and experience with these processes. Although these demonstration programs support second and third generation processes, they will also provide engineering information that may be useful for correcting technical faults and reliability problems that may arise in first generation plants.

Dealing With Other Effects

An important effect of increasing automobile fuel efficiency is the potential for decreased automotive safety due to size and weight reduction. There may also be major employment-related side effects associated with the restructuring of the auto industry and the accompanying accelerated rates of capital investment by the industry. There are familiar policy instruments that can deal with both of these effects. For the safety effects, Congress can choose among safety standards for new cars, educational programs, and support of safety R&D. Employment effects may be eased by minimizing plant relocations (through tax breaks or direct assistance to the industry), or by ameliorating the effects of employment reductions through aid to communities and affected workers and other individuals.

Potential environmental and worker-related problems associated with synfuels development are substantial, and there is cause for concern about the adequacy of future regulation of the synfuels industry. The Government can help to assure that the private sector takes account of these problems. Specific areas worthy of congressional attention include: the environmental research and regulatory programs of the Environmental Protection Agency (EPA), DOE, the Office of Surface Mining, and the Occupational Safety and Health Administration, in light of recent budget cuts and changes in program direction; the dismantling of DOE's demonstration program for synfuels technologies; and the progress of SFC in demanding appropriate consideration of siting, monitoring, pollution controls and occupational safety as a condition for financial assistance. Congressional options range from holding oversight hearings to increasing the resources of the environmental regulatory agencies and shifting their program emphases by legislation.

To mitigate the socioeconomic effects on communities from synfuels development, Congress may wish to consider several forms of growth management assistance, including loan guarantees, grants, and technical assistance. Any new Federal initiatives in this area will be complicated, however, by continuing arguments about relative responsibilities of Federal, State, and local governments and private industry. And new initiatives need to be sensitive to the substantial differences from location to location in the severity of impacts and the resources already available for mitigation.

OVERVIEW OF THE IMPORT REDUCTION OPTIONS

Increased Automobile Fuel Efficiency

Automobile fuel efficiency can be increased through a variety of measures, including:

- reductions in vehicle weight;
- improvements in conventional engines, transmissions, and lubricants;
- better control of engine operating parameters;
- new engine and transmission designs;
- reduced aerodynamic drag;
- improvements in accessories; and
- decreases in rolling resistance.

Projections of Fuel Economy

Future oil savings from increased automobile fuel efficiency depend, first, on the magnitude and character of future auto sales. In the past few years, consumer preferences for such fuel-economy-related characteristics as vehicle size and performance have fluctuated while new car sales have dropped significantly. Both the long-term sales average and consumer preference for fuel efficiency will be critical determinants of the rate of penetration of fuel efficiency technology.

Second, in response to changing consumer preferences and foreign competition, the rate of change of vehicle technology has accelerated and old rules about how long it takes to put a new technology into place* are no longer valid. The present rapid rate of replacement of capital equipment puts a great strain on the domestic auto industry. During the next several years, competitive forces will push toward continued rapid technological change, but the financial weakness of the domestic auto industry will pull toward slower technological change. The strength of future foreign competition and consumer perceptions of the future price and availability of gasoline and diesel fuel, among other factors, will influence the balance of these opposing forces, and, consequently, whether rapid increases in fuel efficiency of domestically produced cars continue.

Third, the efficiency increases are not fully predictable. There can be discrepancies between test results and the results obtained in actual use. Technical compromises that affect ultimate performance have to be made to allow better integration with existing equipment, easier and cheaper production and assembly, and resistance to extreme operating conditions and incorrect maintenance procedures. Development problems are not always solved satisfactorily; such problems could occur more frequently if technological change accelerates.

OTA developed projections (table 1) of plausible ranges of average new-car fuel economy based on varying expectations of the relative demand for different-sized cars and the effectiveness and rate of development and introduction of new fuel-economy improvements. As reflected in these projections, both technology and vehicle size are critical factors for future fuel savings. Marketplace uncertainty is reflected even as early as the 1985 projections—manufacturers' plans and the technology are already established, but the projections still range from 30 to 37 mpg* (compared to the 1981 level of 25 mpg).

Table 1.—Projected Average New-Car Fuel Economy,[a] 1985-2000 (mpg)

	1985	1990	1995	2000
No further shift towards smaller cars beyond 1985	30-34	36-45	39-54	43-62
Moderate further shift to smaller cars	30-34	38-48	43-59	51-70
Rapid shift to small cars	33-37	43-53	49-65	58-78

[a] Based on EPA city/highway (55/45 percent) cycle. Each of the mileage ranges (e.g., 30-34) reflects relative expectations of the performance and rate of development and deployment of new technologies. The lower value represents OTA's "low estimate" scenario, the upper value represents a "high estimate" scenario.

SOURCE: Office of Technology Assessment.

Note on Table 1: Can We Do Better?

The projections in table 1 do not represent the *technological* limit of what could be achieved in this century. The most efficient automobiles in each size class are likely to achieve considerably better fuel economy than the average; for example, technologies are available that probably can allow a new-car fleet average of 60 mpg by the mid-1990's with the same mix of vehicle sizes as today's and adequate vehicle performance (compared with the table's 1995 "same size mix" projection of 39 to 54 mpg). *This ignores consumer preferences for vehicle features that conflict with fuel economy maximization, however.* By the same argument, the 1981 new-car fleet average *could have been* 33 mpg if consumers had consistently chosen the most efficient vehicle in each of the nine EPA size classes and producers had been able to meet the demand. Instead, the actual 1981 model average to January 1981 was 25 mpg.

Interestingly enough, if consumers had chosen only the most fuel-efficient gasoline-powered automobiles in each size class, over 90 percent of the vehicles would have been U.S.-manufactured cars or captive imports. The market problems of U.S. manufacturers in 1981 cannot be traced primarily to an inability of U.S. manufacturers to produce fuel-efficient cars, but depend on factors such as differences in perceived value between American and imported automobiles.

The difference between *average fuel efficiency,* which is a function of consumer preference, and *potential fuel efficiency,* which assumes that every car in the fleet embodies the most fuel-efficient choice of technologies available, is critical to understanding why OTA's projections may differ from other projections that apply a single choice of technologies to the entire fleet. The latter assumption is realistic only if future consumers value fuel economy, relative to other automobile attributes, much higher than they do today.

How much fuel can be saved by improved fuel economy? Assuming 30 mpg as a base and using the projections in table 1, **continued developments in automobile fuel efficiency could save 0.6 to 1.3 MMB/D of oil by 2000.** The lower value represents pessimistic expectations about the advance of automobile technology and the shift towards smaller cars; the higher value represents optimistic technological expectations and continued substantial shifts to small cars. **Contin-**

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*For example, previous assumptions were: 5 years to move from initial production decision to introduction of a technology in a model line; 5 to 10 years to diffuse the technology throughout the new car fleet; and 10 to 15 years of production to pay for the investment. The estimate of 5 years to move from initial production decision to introduction may now be a bit too low, while increased rate of change of vehicle technology would necessarily reduce the other two estimates.

*Based on a weighted average of 55 percent EPA city test cycle and 45 percent EPA highway cycle, the formula used to measure compliance with currently mandated CAFE requirements.

ued diffusion of these technologies into the overall fleet could save 0.8 to 1.7 MMB/D by 2010 with no further technological advances beyond 2000.*

Costs

OTA's cost analysis of auto fuel-efficiency improvements concentrates on investment costs in total dollars as well as dollars per barrel per day of oil saved. Estimates of the costs for associated technology and product development are included in the investment costs,** because they are part of the normal outlays needed to put any new vehicle in production and represent a sizable fraction of the fixed costs (i.e., costs independent of production levels).

It is not possible to make highly accurate estimates of the investment costs (per barrel per day of oil saved), due to the uncertainty associated with predicting actual efficiency increases that will be achieved. In addition, the cost of developing technologies to the point where they can be reliably mass-produced has been highly variable and is difficult to predict.

Accurate cost estimation also is complicated by the difficulty of separating the cost of increasing fuel efficiency from the other costs of doing business. Increases in fuel efficiency are inextricably intertwined with other changes in the car. For example, the engine redesign for fuel efficiency may incorporate other changes, to improve other automobile attributes, at little additional cost. Design changes that increase efficiency may improve or degrade other attributes such as emissions or performance.

If it is the industry's judgment that consumers do value fuel efficiency, the normal cycle of capital turnover and vehicle improvement would result in an increase in fuel efficiency automatically. Unfortunately, the "normal" rate of fuel efficiency increase is not really predictable because it depends on marketplace preferences and corporate strategies.

Because of the difficulty of separating out the marginal fuel efficiency investments from the "normal" investments, OTA's investment cost estimates (in dollars per barrel per day) in table 2 are the **total** investments (including development costs) **allocated to increasing fuel efficiency,** divided by the total fuel savings rate expected. (See footnote c of table 2 for the details of the cost allocation.) These investment rates may be somewhat lower than the marginal rates would be because, in designing their "normal" investment programs, manufacturers probably will select those investments with the highest potential payoff in efficiency increase per dollars spent.

In any case, the range of investment rates for increased fuel efficiency for each time period overlap the rates for investments in synfuels plants (see *Synthetic Fuels* section below), although the 1985-90 fuel-efficiency rates would be lower than the synfuels rates if widespread expectations for overruns in early synfuels investments are proved correct.

The total domestic capital investment associated with increased fuel efficiency would be about $25 billion to $70 billion between 1985 and 2000, or less than $2 billion to $5 billion annually during the period. This level of investment can be compared with recent and projected capital investment by the industry* remembering that part of the fuel-efficiency investment could be included in "normal" capital expenditures if consumer demand for fuel efficiency is high enough. For the period 1968-77, annual capital investment by General Motors (GM), Ford, and Chrysler averaged $6.68 billion in constant 1980 dollars. Investments by these companies rose to $10.4 billion in 1979 and $10.8 billion in 1980, and are projected by some analysts to rise to $12 billion per year during 1980-84. The ability of the domestic industry to maintain their expected schedule of capital expenditures is dependent on

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*Assuming 1.26 trillion vehicle miles (automobile only) traveled annually in 2000, 1.31 trillion in 2010, and an on-the-road fuel efficiency 10 percent less than EPA rated fuel efficiency.

**In this context, development means all of the engineering activities needed to prove a design concept and determine how it can best be integrated into the vehicle system and mass-produced.

*The two sets of figures are not fully analogous. A portion of the domestic industry's costs are for overseas investments, while a portion of the 1985-2000 fuel efficiency costs will be borne by outside suppliers rather than the major manufacturers.

Table 2.—Domestic[a] Investment for Increased Fuel Efficiency

Time	Car sales (million/yr)	New-car fuel efficiency (mpg)[b]	Efficiency investment[c] (thousand 1980 $/bbl/day)	Total investment[d] (billion 1980 $ during time period)
1985-1990	8.6	38-48	20-60	8-23
1990-1995	8.8	43-59	60-140	9-20
1995-2000	9.1	51-70	50-150	7-18

[a] Assumes 75 percent of all cars sold are manufactured domestically.
[b] Fleet average miles per gallon at end of time period, with moderate shift in demand to smaller cars.
[c] Represents costs allocated to fuel efficiency, including associated development costs of 40 percent of capital spending. Investment was allocated in the following way: 50 percent of the total engine investment is assumed to be for fuel efficiency; 75 percent of the total investment for conventional transmissions is for fuel efficiency; and all of the investment for advanced materials substitution, automatic engine on/off, and energy storage devices is for fuel efficiency.
[d] Includes all capital costs associated with fuel efficiency, including fraction allocated to other attributes, but excluding development costs.

SOURCE: Office of Technology Assessment.

a resumption of their former levels of sales and profitability. There are already signs that U.S. auto manufacturers are beginning to cut back on planned investments in the face of continued poor sales and declining cash reserves.

If consumer demand for fuel efficiency is consistently strong, domestic manufacturers are likely to respond by **at least** incorporating into their "normal"* rate of capital turnover as many fuel-efficiency features as possible. If capital turnover is limited to its historical "normal" rates, then the fuel efficiencies shown in table 1 could still be achieved, but it would take longer to implement the changes than is indicated by the schedules shown in that table. In particular, implementation of the low scenario could require 25 percent longer (relative to 1985) than the schedule in table 1; and the high scenarios could require 45 percent longer. Whether the high or the low scenario is eventually achieved, however, also depends on the success of technical developments.

If demand for fuel efficiency were high enough, however, the manufacturers would increase their redesign/replacement rates. By adding $5 billion to $10 billion in capital expenditures during 1985-2000, or $0.3 billion to $0.7 billion per year (5 to 10 percent above "normal"), capital turnover can be speeded up to allow the low scenarios to be achieved on the schedule in table 1. Similarly, if technology developments are successful, the high scenario could be achieved as shown in table 1 with capital expenditures of $9 billion to $23 billion above "normal" during the period 1985-2000, or $0.6 billion to $1.5 billion per year (10 to 20 percent above "normal").

If future demand for fuel efficiency is not high enough to support these rates of change, increases in fuel efficiency will be further delayed unless required by new CAFE standards. On the other hand, CAFE standards **without** analogously high consumer demand for efficiency would require the manufacturers to either defer expenditures for other improvements that might help car sales or to incur additional capital costs.

The consumer costs of increased fuel efficiency, measured in dollars per gallon of gasoline saved, are speculative because the variable costs —mostly material and labor costs—are even more difficult than investment costs to determine accurately. OTA's analysis is based on alternative assumptions about the degree of change in material and labor costs. A direct calculation of these costs would have been expensive and the results difficult to defend because the source data is proprietary and highly dependent on judgments about the success of adapting technologies to mass production. Table 3 shows the range of costs attributed to fuel efficiency assuming that consumers value future gasoline savings as highly as today's savings (i.e., without discounting future savings*) and that manufacturers pass through the full costs. Conceivably, foreign competition could force the manufacturers to absorb part of these costs.

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*Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced-materials substitution.

*The cost perceived by consumers would be about 2.5 times as high as those shown if the consumer discounts future fuel savings at 25 percent per year, i.e., each future year's savings during the life of the car is valued at 25 percent less than the previous year's savings.

Table 3.—Consumer Costs for Increased Automobile Fuel Efficiency, Without Discounting Future Fuel Savings, Moderate Shift to Smaller Cars

Time period	Average new-car fuel efficiency at end of time period (mpg)	Consumer cost[a] ($/gal saved)	
		No variable cost increase	High variable cost[b] increase
1985-1990	38-48	0.15-0.40	0.40-1.10
1990-1995	43-59	0.35-0.85	1.10-2.60
1995-2000	51-70	0.30-0.95	0.90-2.80

[a] Assumes a capital recovery factor per year of 0.15 times the capital investment allocated to fuel efficiency.
[b] Assumes variable cost increase is twice the capital charges associated with the capital investments allocated to fuel efficiency.

SOURCE: Office of Technology Assessment.

The consumer costs of fuel efficiency range from values that are easily competitive with today's gasoline prices to values that are considerably higher, depending on the efficiency gains actually achieved, the success of developing production techniques that can hold down variable cost increases, and the value consumers place on future fuel savings. Investments for increased efficiency for the 1990-2000 model years will look particularly risky if the current soft petroleum market continues for a few more years, or if auto manufacturers have difficulty holding down their labor and materials costs.

Another important measure of the cost to consumers of increased fuel efficiency is the increase in the price of new cars required to recover the industry's increased production costs. If the market demand for fuel efficiency is strong enough to ensure that as much as possible of the capital investment for fuel efficiency increases is incorporated into the normal capital turnover, and if the variable costs of production can be held constant, then the cost* of achieving OTA's fuel-efficiency scenarios can be as low as $60 to $130 per car during the 1985-2000 time period. Under these conditions, an average of 35 to 45 mpg could be achieved by 1990 without increasing new-car costs.

If actual market demand for fuel efficiency is not this high, automakers would be unlikely to incorporate a very high level of fuel efficiency investments into their normal capital turnover. Also, the variable costs of production **are** likely to rise somewhat. The "upper bound" for added costs—assuming large increases in variable costs and **no market-driven** investment for fuel efficiency increases beyond 1985—is $800 to $2,300 per car during the 1985-2000 period, and $250 to $500 per car to achieve 35 to 45 mpg by 1990. Therefore, the cost per car of increased fuel efficiency beyond 1985 ranges from "clearly competitive" to "probably unacceptable."

Economic Impacts

The domestic automobile industry is in the midst of a massive investment program aimed at improving the competitiveness of American automobiles. These expenditures are associated with important structural changes in the industry; and accelerating the rate of capital turnover (for increased fuel efficiency or other reasons) may accelerate some of these trends.

Manufacturers are closing older, inefficient plants and building new ones that incorporate extensive use of robots and other labor-saving technology to increase productivity. For a number of reasons, including lower labor and other costs, many of the new facilities may be built in the Nation's Sun Belt or overseas rather than in the current North-Central auto manufacturing centers, although recent labor concessions may change this picture. Because of a shift in U.S. demand to smaller cars, which can be marketed more universally, the incentive to produce in the United States is diminishing. Finally, because rapid capital turnover is raising production costs at a time when consumer demand for automobiles has been sluggish, manufacturer profits have diminished and it has become harder for the firms to secure capital at affordable costs.

American companies are forging more extensive ties with foreign manufacturers to design, produce, and market fuel-efficient cars, and are moving towards producing more nearly standardized automobiles that can compete in international markets. Current trends seem to be toward fewer separate automotive manufacturing and supply firms worldwide; only GM and Ford appear to be reasonably certain of remaining predominantly American-owned.

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*Assumes a capital recovery factor of 0.15.

Certain regions such as the industrial Midwest —and the Nation as a whole—will lose jobs if these structural changes continue. Job losses also would occur, however, if the process is interrupted, because the restructuring represents the industry's response to the conditions that caused its present market problems, and it clearly is aimed at regaining sales.

Social Impacts

As auto manufacturing and supply activities become more efficient and automated, there will be important changes in the workplace environment. Robots and other automated equipment will increasingly be used for the more routine and dangerous jobs, and skilled workers such as engineers and maintenance technicians should become a greater percentage of the smaller total work force. Shifting manufacturing overseas will reduce U.S. employment in primary manufacturing as well as in supplier companies. Although employment losses may be larger in the supplier industries, the effects in these industries will be distributed over a larger geographical area. Employment in related activities such as repair and service will change to accommodate the new auto characteristics—e.g., repairs of plastic body components require adhesives, not welding—and the increasing sophistication and capital investment required for vehicle maintenance will place new demands on shops and dealers.

Fuel efficiency increases also affect automobile owners by changing the physical attributes of the vehicle and the economics of owning cars. For example, a continued reduction in car size could lead to increasing use of rentals for longer trips or for occasional requirements for increased cargo-carrying capacity. Increases in the initial cost of buying a car are likely to lead to a continuation of current trends of keeping cars longer, resulting in a slower growth or reduction in new-car sales.

Environment, Health, and Safety

Increasing automobile fuel efficiency appears likely to have a relatively benign effect on the natural environment and public health, because most of the efficiency measures have few adverse effects on auto emissions, emissions associated with vehicle manufacturing, etc. An important exception may be any shift to widespread use of diesel engines, which could cause problems with vehicle particulate and nitrogen oxide (NO_x) emissions. Also, the increased production of lightweight materials—particularly aluminum—may cause additional impacts, such as increased energy consumption in processing and increased demand for bauxite. On the other hand, significant downsizing of automobiles could allow either lower vehicle emissions or lower control costs to maintain current emission levels.

In contrast to their expected small effect on pollution levels, fuel conservation measures that stress reducing vehicle size may have a significant adverse effect on vehicle safety. This is because of the important role in crash survival played by "crush space"* and other size- and weight-related factors. Even a relatively small decline in vehicle safety could cause hundreds or even thousands of additional deaths and serious injuries per year.

There is no widely accepted estimate of the magnitude of this effect. The National Highway Traffic Safety Administration has projected a 10,000 per year increase in traffic deaths from vehicle size reductions by 1990, but this is based on a limited data set and a number of simplifying assumptions. And a net increase in traffic deaths is not inevitable, since increased usage of passenger restraints and improvements in vehicle design could more than offset the effect of moderate size reductions.

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*With a smaller "crush space" (thus, more rapid deceleration of occupants in a crash), factors such as seatbelt and shoulder restraint usage, better driver training and traffic control, and other safety measures, become more important determinants of traffic safety.

Synthetic Fuels

Production of a variety of fossil fuel-based synthetic fuels is planned or under development.

- Oil shale can be heated to release a liquid hydrocarbon material contained in the shale. After further upgrading a **synthetic crude oil** similar to high-quality natural crude oil can be produced. This can be refined into gasoline, diesel and jet fuels, fuel oils, and other products.
- Coal can be partially burned in the presence of steam to produce a so-called "synthesis" gas of carbon monoxide and hydrogen, from which **gasoline, methanol, diesel and jet fuel, and other liquid fuel products** ("indirect liquefaction") or **synthetic natural gas** (SNG) can be produced.
- Coal also can be reacted directly with hydrogen (which is itself generated from a reaction of steam and coal) to produce a **synthetic crude oil** ("direct liquefaction"). This oil can be converted to **gasoline, jet fuel and other products** in specially equipped refineries.

Projection of Synfuels Development

The principal technical deterrent to rapid deployment of a synfuels industry is the lack of proven commercial-scale synfuels processes in the United States. Shale oil, indirect coal liquefaction, and SNG processes currently are sufficiently developed that the demonstration of commercial-scale process units or modules is being pursued, but these first units are likely to require considerable modification before they can operate satisfactorily. Once these commercial-scale modules have been adequately demonstrated, full-size commercial facilities can be constructed (from several modules). In contrast, direct coal liquefaction requires further development before commercialization and probably will not contribute significantly to the synfuels industry before the mid to late 1990's. A major technical obstacle, the handling of high levels of solids in the process streams, is not now understood well enough to allow developers to move directly to commercial- from small-scale units now in operation.

Normal planning, permitting, and construction may take 7 to 8 years for a large synfuels plant, with the last 5 years or so devoted to construction. Consequently, a first round of commercial-scale plants conceivably could be operating by the late 1980's, although these would be quite vulnerable to delays and cost overruns. Beginning a second round of construction before the first set of plants has been fully demonstrated would risk additional costly revisions and delays.

In addition to scheduling constraints caused by technological readiness, shortages of experienced manpower (primarily chemical engineers and project managers) could constrain the pace of synfuels development. On the other hand, problems stemming from shortages of skilled craftsmen, construction materials, or specialized equipment probably can be averted because of the long leadtime before they are needed in large numbers. However, some metals needed for certain steel alloys are obtained almost exclusively from foreign sources.

Many variables affect the rate of development, and predictions are extremely speculative. It is OTA's judgment that **under favorable circumstances, fossil fuel-based production of synthetic transportation fuels could be 0.3 to 0.7 MMB/D by 1990, growing to 1 to 5 MMB/D by 2000,** depending on the success of the first round of synfuels plants and the fraction of those plants that produce **transportation fuels** as opposed to fuel gases or fuel oils. Achievement of 0.3 MMB/D by 1990 assumes that a sizable commercialization program, such as that being pursued by the Synthetic Fuels Corp., is carried out, but that technical problems limit total production; 0.7 MMB/D would require an increased number of plant commitments within the next year or so, a virtually complete emphasis on liquid transportation fuels, and a high level of technical success with the first plants.

It must be stressed that even the "low" 0.3 MMB/D production level may be considered as optimistic in light of current expectations of at least short-term stability in oil prices, as well as remaining technical and environmental uncertainties. In addition, the dismantling of DOE's demonstration program may increase the perceived and actual technological risks of synfuels development. Thus, **the goals of the National Synfuels Production Program, created by Congress in 1980—0.5 MMB/D by 1987 and 2 MMB/D by 1992—appear unattainable without a crash program that would involve extraordinary technical and economic risks and extensive Government intervention.**

Costs

The costs of synfuels are uncertain. First, the factors that limit rapid deployment of the industry also affect its costs. Technical uncertainties complicate cost evaluation, and long shakedown times and potential construction delays would be very expensive at prevailing interest rates. Second, synfuels' relatively high capital costs mean that their total costs are especially sensitive to the type of financing used, the level of interest rates, and the rate of return required by the investors. The present high level of uncertainty in capital markets therefore translates into a high level of cost uncertainty. In addition, the long construction times associated with synfuels plants make them vulnerable to hyperinflation.*

OTA has projected synthetic fuel costs based on the best available cost estimates in the public literature and OTA's previous oil shale study.[1] These sources indicate that, if the potential for cost overruns is not considered, the capital investment (in 1980 dollars) for a 50,000 bbl/d (rated capacity) synthetic fuels plant will range from $2.1 billion to $3.3 billion, or $47,000 to $73,000/bbl/d of production (assuming the plant produces at 90 percent of rated daily capacity). Total plant investments for a 5 MMB/D synfuels industry would thus be about $250 billion to $400 billion. Based on past experience, however, there is a very high probability that final costs will be greater than these ranges.

For example, an extrapolation from recent cost overruns in the chemical industry widens the single plant (50,000 bbl/d) range to $2.3 billion to $4.7 billion (excluding direct liquefaction, for which cost estimates are less reliable), or about $50,000 to $110,000/bbl/d. Other related investments (e.g., coal mining) raise the total to $50,000 to $125,000/bbl/d. The investment costs per barrel per day of production may be further inflated by performance levels below the 90-percent design factor, although presumably this will be a problem only with first generation plants.

The actual selling price of synthetic fuels will be determined in the marketplace by the prices of competing fuels regardless of the costs of production. Using the projected synfuels production costs, however, OTA calculated the price that service stations **would have to charge** in order for the synfuels producer to attain a required return on investment. Table 4 displays these "prices" for a few alternative combinations of financing and real* return on investment.

Based on these estimates, it is clear that **companies that must bear the full investment burden of a new synfuels plant are unlikely to invest in synthetic fuels production unless: 1) they view this investment as one of low risk and worthy of a low expected return on investment, 2) they expect fuel prices to rise very sharply in the future, or 3) they are willing to take a loss or low return to secure an early market share. The first alternative is not credible for the first generation of commercial plants.**

With the large (75 percent of project costs) loan guarantees that are possible under the En-

Table 4.—Price of Synthetic Fuels Required To Sustain Production Costs[a] (1980 $/gal of gasoline equivalent)

Price (pretax)	Financing	Real return equity investment
$0.80-$1.10...	100% equity	5%
$1.30-$1.60...	100% equity	10%
$1.70-$2.40...	100% equity	15%
$0.80-$1.10...	25% equity, 75% debt	10%

[a] Assumptions: no cost overruns, $1.20/million Btu coal, 5 percent real interest rate on debt financing, $.20/gallon distribution cost including retailer profit. For more details, see ch. 8, table

SOURCE: Office of Technology Assessment.

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*Hyperinflation in construction costs of major capital projects is a relatively recent phenomenon, however, and some industry analysts consider it a temporary aberration.

[1] U.S. Congress, Office of Technology Assessment, *An Assessment of Oil Shale Technologies*, OTA-M-118 (Washington, D.C.: U.S. Government Printing Office, June 1980).

*The real rate of return is the nominal rate of return minus the inflation rate.

ergy Security Act,* however, investments in synthetic fuels appear to be attractive even at 1981 fuel prices, but only if current capital cost estimates for synfuels plants are correct and there are no cost overruns. Most industry experts, however, consider the chances of substantial cost overruns to be high. A cost overrun in plant investment of 50 percent would increase the necessary price of synfuels by 20 to 30 percent, or else reduce the return on investment.

OTA's cost analysis implies that **significant levels of investment in synfuels production are unlikely at this time without the kinds of financial incentives offered by SFC.** Of course, a further—and currently unexpected—rapid escalation in oil prices could change this conclusion.

Uncertainties associated with the cost estimates are too large to allow in-depth comparison of the costs of the various synfuels. Also, in OTA's opinion, significant reduction of these uncertainties cannot be achieved by further study but will require actual plant construction. **There are indications, however, that shale oil and methanol from coal could be the least expensive options for producing transportation fuels.** Shale oil plants are less complex technically than other synfuels processes and shale oil is relatively easy to refine, thereby suggesting a lower cost. Methanol's high octane and burning characteristics make it more efficient than gasoline in specially designed engines. But materials-handling problems for oil shale, engine technology developments that could offset methanol's efficiency advantage, and unforeseen requirements for process changes could negate these apparent advantages.

Economic Impacts

Development of a fossil fuel-based synthetic fuels industry could create a major new economic activity in the United States, particularly in areas with large reserves of coal or oil shale. There are potential drawbacks, though. For example, because of synfuel plants' long lifetimes and construction leadtimes, a liquid fuel supply industry based largely on synfuels would be less able than a natural petroleum-based industry to respond quickly to changing market conditions. Rapid synfuels deployment would create a risk that unforeseen market changes could leave the United States with an outdated, idle, capital-intensive industry.

Development of the industry will have other important consequences. For instance, because of the large capital, technical and marketing requirements, and the high risks, small companies are unlikely to enter the market except as parts of consortia. This contrasts sharply with the large number of small-scale producers currently involved in oil and gas development, although ownership concentration in the oil and gas industry will grow in any case as the more easily recovered resources are depleted.

Rapid deployment of a synfuels industry could lead to temporary shortages of equipment, materials, and personnel, which in turn can lead to construction bottlenecks and local inflation. However, long-term inflationary effects are not expected to be large because, in general, the leadtime is sufficient to expand production capacity and labor supply. An important exception may be the supply of experienced chemical engineers and project managers. If shortages of these personnel develop, poor project management or improper plant design could lengthen construction schedules, delay plant startup, and increase costs for chemical plants and oil refineries as well as synfuels plants.

The financial requirements for rapid growth are very large. For example, the rate of investment required to achieve 5 MMB/D of synfuels by 2000 is likely to be greater than $30 billion per year* after the first few years, about as much capital as was spent for all U.S. oil and gas exploration and development in 1979. Making this large a commitment to synfuels would likely divert some investment capital away from conventional oil and gas exploration and development; and this could reduce conventional domestic oil production below the 7 MMB/D assumed for 2000.

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*The loan guarantees not only allow synfuels developers to borrow money at somewhat lower interest rates than without them, but the 75 percent debt level is considerably higher than the industry average of about 30 percent. Also, in some cases, the loan guarantee may be necessary to secure any debt capital at all.

*OTA's analysis of reducing stationary uses of fuel oil was done primarily to provide a reference point and was less extensive than its analysis of synfuels and increased automotive fuel efficiency.

Social Impacts

The principal social consequences of developing a synthetic fuels industry stem from shifting large numbers of workers and their families in and out of local areas as development proceeds. These population shifts disproportionately affect small, rural communities such as those that predominate in the oil shale and some of the coal areas. High population growth rates can lead to disruptions and breakdowns in social institutions; systems for planning, managing, and financing public services; local business activities; and labor, capital, and housing markets. Whether the growth rates can be accommodated depends on both **community** factors (e.g., size, location, tax base, management skills, and availability of developable land), and **technology-related** factors (e.g., the type of synfuels facilities, the timing of development, and labor requirements).

On the other hand, communities should realize social benefits from synfuels development, e.g., increased wages and profits and an expanding tax base. A significant portion of these benefits may not be realized, however, until after the plant is built. In the meantime, the community must make significant expenditures and the overall impact depends substantially on the existence of effective mechanisms to provide the "front end" resources needed to cope with rapid growth.

Environment, Health, and Safety

The production of large quantities (2 MMB/D or more) of liquid synthetic fuels carries a significant risk of adverse environmental and occupational health effects, some of which are quite dependent on the effectiveness of as yet unproven control measures.

The industry will cause many of the same kinds of mining, air quality, solid waste disposal, water use, and population effects as are now associated with coal-fired electric power generation and other forms of conventional coal combustion. Table 5 shows the amount of new coal-fired power generation that would produce the same effects as a 50,000-bbl/d coal-based synthetic fuels plant, and also directly compares the effects of this plant with a 3,000-MWe coal-fired powerplant. In general, **the emissions of combustion-related pollutants, especially the acid rain precursors sulfur dioxide (SO_2) and NO_x, and the water use of the synfuels plant are significantly lower than for a powerplant processing the same amount of coal.**

To place these effects into perspective, actual coal-fired generating capacity in the United States is about 220,000 megawatts (MW), and about 200,000 MW are expected to be added by 1995. In comparison, SO_2 and NO_x emissions from a 2 MMB/D coal-based synfuels industry would be equivalent to emissions from less than 25,000 MW of power generation, and water use would be equivalent to that of 30,000 MW or less if conservation practices were followed.

On the other hand, **a 2-MMB/D industry (equivalent in coal consumption to 110,000 to 160,000 MW of coal-fired electric generating capacity) would mine hundreds of millions of tons of coal each year, with attendant impacts on acid drainage, reclamation, subsidence and occupational health and safety, and would have substantial population-related impacts such as severe recreational and hunting pressures on fragile Western ecosystems.**

Oil shale development using aboveground retorts has the added problem of disposing of large quantities of spent shale. Although successful short-term stabilization of shale piles has been achieved on a small scale, uncertainty remains about the long-term effects of full-scale development. **The major concern about shale disposal as well as in-situ shale processing is the potential for contamination of ground waters.**

Despite the relatively moderate level of emissions per unit of production, an intense concentration of synfuels development within relatively small areas may yield air quality problems and violations of existing air quality regulations. Such concentration is more likely with oil shale, because of the concentrated resource base. As a result, air quality restrictions may limit oil shale development to under 1 MMB/D unless there are changes in the restrictions or improvements in

Table 5.—Two Comparisons of the Environmental Impacts of Coal-Based Synfuels Production and Coal-Fired Electric Generation[a]

Type of impact	A. Coal-fired generating capacity that would produce the same impact as a 50,000 bbl/d coal-based synfuels plant (MW(e))	B. Side-by-side comparison of environmental impact parameters		
		3,000 MW(e) generator	50,000 bbl/d synfuels	Units
Annual coal use	2,500-3,600[b]	6.4-15.0	5.3-17.9	million tons/yr
Annual solid waste	(2,500-3,600) ±[c]	0.9-2.0 +	0.6-1.8 +	million tons/yr
Annual water use:				acre-ft/yr
Current industry estimate	640-1,300	25,000	5,400-10,800	
Conservation case	400-700		3,400-5,900	
Annual emissions:				tons/yr
Particulates	120-2,800	2,700	100-2,500	
Sulfur oxides	90-500	27,000-108,000	1,600-9,900	
Nitrogen oxides	60-300	63,000	1,600-7,800	
Hourly emissions:				lb/hr
Particulates	90-2,200	880	30-800	
Sulfur oxides	70-40	8,800-35,200	500-3,200	
Nitrogen oxides	60-300	20,500	500-2,500	
Peak labor	4,100-8,000	2,550	3,500-6,800	persons
Operating labor	2,500	440	360	persons

[a] In example A, the powerplant uses the same coal as the synfuels plant, new source performance standards (NSPS) apply, sulfur oxide emissions assumed to be 0.6 lb/10^6 Btu. In B, NSPS also apply but sulfur oxide emissions can range from 0.3-1.2 lb/10^6 Btu. In both cases, the synfuels plant parameters represent a range of technologies, with a capacity factor of 90 percent and an efficiency range of 45 to 65 percent; the powerplant is a baseload plant, with a capacity factor of 70 percent, efficiency of 35 percent. The major data source for this table was M. A. Chartock, et al., *Environmental Issues of Synthetic Transportation Fuels From Coal: Background Report.* University of Oklahoma Science and Public Policy Program, contractor report to OTA, July 1981.

[b] In other words, the amount of coal—and thus, the amount of mining—needed to fuel a 50,000 bbl/d synfuels plant is the same as that required for a 2,500-3,600 MW(e) powerplant.

[c] A synfuels plant will have about as much ash to dispose of as a coal-fired powerplant using the same amount of coal. It may have less scrubber sludge, but it may have to dispose of spent catalyst material that has no analog in the power plant . . . thus the ±.

SOURCE: Office of Technology Assessment.

control technology. In most cases, however, the restrictions do not involve possible violations of the health standards, but rather visibility or other standards.

Aside from these effects, **synfuels development creates a potential for occupational, ecological, and public health damage from the escape of toxic substances formed during the conversion processes.** These include cancer-causing organic compounds, chemically reduced sulfur and nitrogen compounds, and inorganic trace elements. The occupational risks, generally acknowledged as the most serious, are mainly associated with "fugitive" emissions and leaks from valves, gaskets, etc., and with the handling of fuels and plant cleaning. The major ecological and public health risks are associated with contamination of surface and ground waters—from inadequate treatment of wastewaters, leakage from holding ponds or solid-waste landfills, and disruption of aquifers by mining operations—as well as with spills and exposure to contaminated fuels. Fugitive emissions and leaks from the plants also pose some risk to public health, but at a far lower level than to the plant workers; a potentially important impact of the public's exposure to these substances, however, is likely to be discomfort from their odor.

The risks associated with these toxic substances, although possibly the most serious of synfuels' potential environmental risks, are **not** quantifiable at this time. However, it does appear possible to differentiate, at least tentatively, among some of the basic process groupings in terms of their comparative risk. Direct processes (e.g., Exxon Donor-Solvent, SRC II) appear to present the greatest risk because of their comparatively large number of potential sites for fugitive emissions, high production of toxic hydrocarbons, and abrasive process streams. Indirect processes using low-temperature gasifiers (such as Lurgi) may be intermediate in risk because they produce relatively large quantities of toxic hydrocarbons. Indirect processes using high-temperature gasifiers (e.g., Koppers-Totzek, Shell, Texaco) appear to be the cleanest group of coal-based processes. Finally, if the risks from spent shale are excluded, the risks from toxics yielded by oil shale processes probably are no worse than those of indirect, high-temperature coal processes.

There is little doubt that it is **technically** feasible to moderate a synfuels industry's adverse impacts to the satisfaction of most parties-of-interest. In OTA's judgment, however, **despite substantial industry efforts to minimize adverse impacts, the environmental risks associated with toxic substances generated by synthetic fuels production are significant and warrant careful Government attention.**

Current development plans and existing legislation call for strong measures to reduce many of the potential adverse environmental impacts from synfuels plants through intensive application of emission controls, water treatment devices, protective clothing for workers, monitoring for fugitive emissions, and other measures. Virtually all of these measures have been adapted from controls used with some success in the petroleum refining, petrochemical, coal-tar processing, and electric power-generation industries. Synfuels industry spokesmen are confident that the planned controls will adequately protect worker and public health and safety as well as the environment.

Spokesmen for labor and environmental organizations are far less confident, however, and there remain important areas of doubt concerning the adequacy of environmental management. The full range of synfuels impacts—especially those associated with the toxic substances created or released in the conversion processes—may not be effectively regulated. Existing regulations do not cover many of these toxic substances, and extending regulatory controls to provide full coverage will be difficult. Critical stumbling blocks are the large number of separate compounds that must be controlled, and the recent reductions in the budgets of Federal environmental agencies and deemphasis of their synfuels research programs. Detecting synfuels environmental damages and tracing them to their sources—a key requirement in establishing and enforcing control standards—may be difficult because many of the damages will occur slowly and the relationship between cause and effect is complex.

Another important concern is the possibility that the industry's environmental control efforts may not be sufficient to avoid environmental surprises. Federal Government personnel are concerned that many developers are focusing their control programs on meeting immediate regulatory requirements and are reluctant to commit resources to studying and controlling currently unregulated pollutants. Also, despite pollution control engineers' optimism that all synfuels waste streams are amenable to adequate cleanup, there are still doubts about the reliability of proposed control systems. These doubts are aggravated by differences in process conditions and waste streams between synfuels plants and the refineries, coke ovens, and other facilities from which the proposed controls have been borrowed, and also by a lack of testing experience with integrated control systems.

Water Availability for Synfuels Development

When aggregated nationally, water requirements for synfuels development are small (producing 2 MMB/D oil equivalent requires only about 0.2 percent of estimated total current national freshwater consumption). Nevertheless, these requirements may have significant impacts on competing water uses. In each of the river basins where major coal and oil shale resources are located, there are hydrologic as well as political, institutional, and legal constraints and uncertainties involving water use (e.g., conflicts over the use of Federal storage, Federal reserved water rights including Indian water rights claims, interstate and international compacts and treaties, State water laws). In addition, existing water resource studies vary in the extent they consider water availability factors and cumulative impacts.

Given the uncertainties that surround the question of water availability generally, only limited conclusions about possible constraints on future synfuels development can be drawn. This is especially true in areas where institutional rather than market mechanisms play a dominant role in obtaining and transferring water rights. Where efficient markets do exist, however, water is not likely to constrain synfuels development because developers can afford to pay a relatively high price for water rights.

In the major Eastern river basins where coal reserves are located (the Ohio, Tennessee, and Upper Mississippi River Basins), **water should be adequate on the main rivers and large tributaries,** without new storage, to support planned synfuels development. In the absence of appropriate water planning and management, however, **localized water shortages could arise during abnormally dry periods or from development on smaller tributaries.**

In the West, competition for water already exists and is expected to intensify with or without synfuels development. In the coal-rich **Upper Missouri River Basin,** the magnitude of the legal and political uncertainties, together with the need for major new water storage projects to average-out seasonal and yearly streamflow variations, **make it impossible to reach an unqualified conclusion as to the availability of water for synfuels development.**

In the **Upper Colorado River Basin,** where both oil shale and coal are located, **water could be made available to support initial synfuels development—as much as a few hundred thousand barrels per day of synfuels production by 1990**—but political and legal uncertainties in the basin make it difficult to determine which sources would be used and the actual amount of water that would be made available. Water availability after 1990 will depend both on how these uncertainties are resolved and on the expected continuing growth in other uses of water.

Reducing Stationary Uses of Oil

Stationary uses of oil include space heating and cooling of buildings, electricity generation, production of industrial process heat, and use as a chemical feedstock. These currently account for nearly half of the oil used in the United States—about 8.1 MMB/D out of a total of 16.8 MMB/D in 1980. Of this, about 4.4 MMB/D are fuel oils—middle distillates and residual oil. The remainder include liquefied petroleum gas, asphalt, petroleum coke, refinery-still gas, and petrochemical feedstocks.

Only reductions in the fuel oil portion of the stationary oil uses are likely to lead to actual reductions in imports. The other oil products are difficult to upgrade to premium fuels or use directly in transportation applications and, consequently, a reduction in their use probably would have little effect on the supply of transportation fuels. On the other hand, the crude oil fractions normally used to produce residual and distillate fuel oils can instead be converted profitably into transportation fuels by refining.

Reductions in fuel oil use can be accomplished by fuel switching and conservation. In the buildings sector, natural gas and electricity can replace distillate oil, and insulation, furnace improvements, and other conservation measures can reduce fuel use in general. For utilities, conservation in all sectors that use electricity can reduce generation requirements, coal and nuclear can replace residual oil for baseload operation, and natural gas can replace distillate oil in peaking turbines. Industrial oil use can be reduced by increases in process efficiency and fuel switching to coal,* natural gas, and electricity.

Projection of Oil Savings

The Energy Information Administration projects that the fuel oil consumed in stationary uses will decline from today's 4.4 MMB/D to 2.6 MMB/D in 1990, assuming a 1990 price of $41/bbl of oil (1979 dollars). This 2.6 MMB/D is the target for further stationary use reduction OTA has assumed for this study.**

OTA has evaluated two approaches to eliminating the remaining 2.6 MMB/D stationary fuel oil use by 2000. One approach involves total reliance on fuel switching. Table 6 shows the energy needed to displace the 2.6 MMB/D, substituting coal for residual oil and natural gas and/or electricity for distillate oil.

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*The Energy Information Administration has predicted that, by 1990, most of the industrial processes that can use coal (primarily large boilers) will have been converted. Therefore, OTA's calculations of post-1990 fuel-switching opportunities do not include coal switching in the industrial sector.

**If oil prices continue to decline in real dollars or stabilize at current levels, 1990 stationary oil use is likely to be greater than projected.

Table 6.—Summary of Annual Energy Requirement To Displace 2.55 MMB/D of Stationary Fuel Oil Use

Sector	Oil (MMB/D)	replaced by	Coal (10^6 tons)	plus	Gas (tcf)	or	Electricity (10^9 kWh)
Buildings	1.2		—		2.4		425
Industry	0.3		—		0.6		120
Utilities.	0.9 (resid.)		100		—		—
	0.15 (dist.) . .		—		0.3		—
Total	2.55		100		3.3		545

SOURCE: Office of Technology Assessment.

The **technical** capability to accomplish this level of switching depends on two factors. First, if natural gas is to play a major fuel-switching role, production of unconventional gas sources* will be needed. A key to this is the future price of gas. Second, production of additional electricity and switching to coal in utility boilers depends primarily on the utility industry's ability to solve its current financial problems and gain access to capital. Either of these potential constraints could severely restrict fuel switching.

A second approach combines fuel switching with measures to conserve oil, natural gas, and electricity. If conservation measures can save enough natural gas and electricity to replace the (reduced) oil requirement, additional gas and electricity production may not be needed. An analysis by the Solar Energy Research Institute (SERI) indicates that conservation measures in the buildings sector alone could save about 1.5 times as much natural gas and electricity as would be required to replace all remaining stationary uses of distillate and residual fuel oil by 2000.** This combined approach has fewer technical constraints than the "fuel switching only" approach. In OTA's judgment, **a significant fraction of the 2.6 MMB/D of stationary fuel oil use expected in 1990 can be eliminated by 2000 by conservation and fuel switching taken together.**

Despite the lack of absolute constraints, however, it is unrealistic to expect total elimination or near-elimination of stationary fuel oil uses by 2000. First, average capital costs are high enough to discourage those investors who apply a high discount rate to their investments. Second, the site-specific variability and the large number of different types of measures imply that some of the individual measures will be far more expensive than the average.* Third, the record of oil-to-coal switching in industry during the past decade has not been a good one despite apparently favorable economic incentives. Finally, the continued reduction in supplies of high-quality "light" crude may lead to excess supplies of residual oil in the 1990's, driving down its price and making conversion from residual oil to coal uneconomical in some cases. To a certain extent the latter effect will be offset by the economic attractiveness of retrofitting oil refineries to produce less low-priced residual oil and more gasoline, jet fuel, and diesel fuel.

Costs

The investment costs for the two strategies for reducing stationary oil uses are similar. OTA has calculated the investment cost of the strategy that relies mainly on fuel switching to be roughly $230 billion, or an average of $90,000/bbl/d of oil saved. Using SERI's cost analysis, the strategy that combines strong conservation measures and replacement of the remaining oil use with electricity and natural gas was calculated to cost roughly $225 billion, or $88,000/bbl/d of oil saved. The difference between the estimated costs for the two strategies is too small to be meaningful.

Both the investment costs and the operating costs paid by individual investors will vary over an extremely wide range. This is particularly true because the "strategies" are actually a combination of several markedly different kinds of investments. For example, conversion of oil-burning utility boilers to coal has an average investment cost of $74,000/bbl/d of oil replaced, whereas conversion of distillate-using facilities to natural gas averages $114,000/bbl/d (including the cost of obtaining the new gas). Also, the costs of each type of investment will vary from site to site.

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*These sources include tight sands formations, geopressurized methane, coal seam methane, and Devonian shale formations.

**Assuming that all such stationary uses are reduced by conservation as well.

*By the same reasoning, many will be **less** expensive than the average.

Electric Vehicles[2]

Automobiles can be powered by rechargeable batteries that drive an electric motor; indeed, some of the first automobiles used battery-electric powertrains. Present concepts of electric passenger vehicles generally envision small vehicles for commuting or other limited mileage uses, with recharging at night when electricity demand is low.

Projections of Use

OTA does not expect electric cars to play a significant role in passenger transportation in this century. Battery-electric cars are likely to be very expensive, costing about $3,000 more in 1990 than comparable gasoline-fueled autos. And this consumer investment may not yield any savings in fuel costs. If batteries must be replaced every 10,000 miles, as required with current technology, total electricity plus battery costs will actually be considerably higher than gasoline costs for a comparable conventional auto, even at $2.00/gal gasoline prices (1980 dollars).

Another reason that OTA is not optimistic is that progress in electric vehicles remains severely limited by battery performance. Currently available batteries and components require 6 to 12 hours for recharging and limit electric vehicles to a range of less than 100 miles between charges. Acceleration is limited to about 0 to 30 mph in 10 seconds, which is lower than the poorest performing (0 to 40 mph in 10 seconds) gasoline and diesel fuel cars and may not be adequate for many traffic conditions. Although predictions of significant reductions in battery size and weight continue, in OTA's judgment current understanding of battery performance does not permit accurate predictions of future improvements.

Even if sufficient progress is made in battery development to encourage extensive usage of electric cars, **electrification of automobile travel does not offer the same potential for oil savings as the other options.** Under the best of circumstances, **most electric passenger vehicles are likely to be small, limited-performance vehicles that will substitute for small, fuel-efficient conventional autos.** Consequently, **a 20-percent electrification of the auto fleet is not likely to save more than about 0.2 MMB/D.***

Environment, Health, and Safety

If technical developments, severe liquid fuel shortages, and/or Government promotion were to result in significant sales of electric vehicles, the major environmental impacts probably would be the air quality and other effects associated with reducing auto emissions and increasing electricity generation. **The overall effects of widespread use of electric vehicles on urban air quality should be strongly positive, because the electric cars would tend to be clustered in urban areas, many of which have chronic automobile-related air pollution problems that would be eased by the displacement of conventional automobiles.** There would be, however, a small net increase in regional and national emissions of SO_2, because conventional autos have few or no SO_2 emissions to offset the SO_2 emissions from fossil-fueled electric power generation for battery recharging. Additionally, when coal is the fuel source for recharge electricity, the amount of coal mined per unit of oil replaced is comparable to that for synfuels production,** with similar coal mining impacts. Material requirements for batteries could add substantially to the demands for certain minerals, e.g., lead, graphite, and lithium.

Electric passenger vehicles are likely to be small and thus should share safety problems

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[2] See, *Synthetic Fuels for Transportation: The Future Potential of Electric and Hybrid Vehicles—Background Paper No. 1*, OTA-BP-E-13 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1982).

*Assuming no oil is used for electricity production and the average gasoline- or diesel-powered vehicle replaced gets 60 mpg.

**That is, 1 ton of coal yields the same oil savings in either technology.

with small conventional automobiles. Additional safety and health problems may be caused by the batteries, which contain toxic chemicals that may pose occupational problems in manufacturing and recycling and may be hazardous in an accident-caused spill; this latter problem is balanced somewhat by eliminating the fuel tank with its highly flammable contents. Finally, extensive outdoor charging of vehicle batteries may pose public safety problems from the electrocution hazard.

Chapter 2

Introduction

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Chapter 2
Introduction

Petroleum has been at the heart of the Nation's efforts to secure its energy future since the 1973-74 oil embargo. Petroleum products currently supply about 40 percent of total U.S. energy needs, and imports account for approximately 30 percent of total petroleum demand. The increases in the price of imported crude that have occurred since 1972—a barrel of imported crude that was selling for $4.80 in 1972 was selling for $31.40 (both expressed in constant 1980 dollars) as of February 1982—have severely strained the national economy by contributing to domestic inflation and trade deficits and by altering demand patterns.

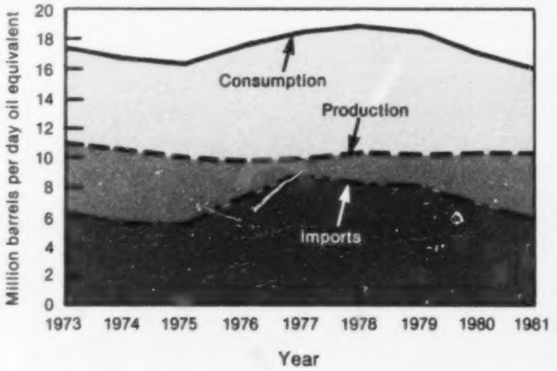
Instead of increasing gradually, petroleum prices have gone up in two large, rapid jumps. These price "shocks" have exacerbated strains on the economy by preventing an orderly adjustment to higher fuel prices. Future price behavior is also very uncertain and complicates economic planning. Subsequent to decontrol of domestic crude oil prices, a continued increase in the price of oil was generally expected. The sharp drop in demand, coupled with reemergence of Iran on the world oil market, however, has created downward pressure on oil prices. A substantial drop in the real price of oil over the next few years is quite possible.

This oil glut will not last indefinitely, however. Indeed, importing nations will eventually again face increasing competition for oil arising from a combination of dwindling world supplies* and increases in demand from both producing and developing nations. This, in turn, will force oil price increases with the possibility that they may again come in the form of price shocks rather than an orderly rise. Thus, the U.S. petroleum problem is not simply that we import oil—indeed, in a stable, economically rational world importing could be economically efficient—but that the supply and price is subject to so much uncertainty and dramatic change.

For 1981, the Nation's imports of crude oil and petroleum products averaged about 5.4 million barrels per day (MMB/D), accounting for about 34 percent of total petroleum demand. These figures compare with 7.5 MMB/D of imports, about 41 percent of total petroleum demand, for 1980. In fact, imports and demand have been on a steady downward trend since their peak in 1978, when imports of 8.2 MMB/D represented 44 percent of total demand (see fig. 3). The principal cause of this downward trend in imports and their share of total petroleum demand was the nearly 120-percent increase in the real price of crude oil since 1978. If the trend were to continue, oil imports could be eliminated by the end of the century.

There is considerable disagreement, however, on whether this trend can be maintained. The current downward trend of prices as a result of a soft market has already been noted. The principal focus of disagreement, however, is the adequacy of the Nation's future domestic supply. The current domestic production of crude oil and natural gas liquids is 10.2 MMB/D. Production of these two liquids has been declining steadily since

Figure 3.—U.S. Petroleum Consumption, Domestic Production, and Imports



SOURCE: Energy Information Administration, U.S. Department of Energy.

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*OTA estimates that non-Communist world oil production could range from 45 to 60 MMB/D in 1990 and 40 to 60 MMB/D in 2000, compared to 46 MMB/D in 1980. While an increase in world production is possible, it is more likely that production will remain fairly stable or slightly decline. See *World Petroleum Availability: 1980-2000—A Technical Memorandum* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1980), OTA-TM-E-5.

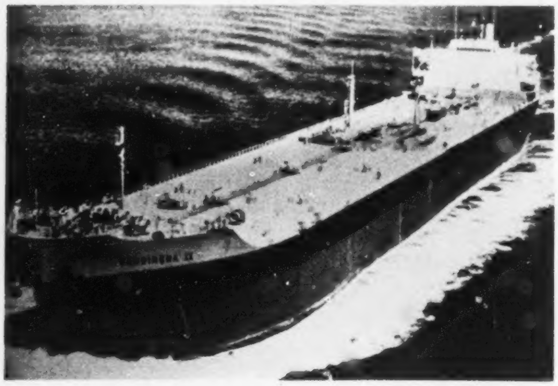

Photo credit: U.S. Department of Energy

Oil tankers deliver most of the crude oil imported to the United States

the peak year of 1970, when it reached 11.3 MMB/D, although the decline has slowed noticeably the last 3 years (see fig. 3). This, coupled with the remarkable upsurge in drilling activity since 1979, has caused some forecasters to predict an increase in production before the end of the century. In its most recent forecast, under a high world oil price scenario, for example, the Energy Information Administration of the Department of Energy forecasts a production rate of 11.2 MMB/D of crude oil and natural gas liquids by 1995.[1]

Despite this increase in drilling and exploration activity, as figure 3 shows, the effect of higher oil prices to this point has been almost exclusively in reducing demand, not increasing supply. In addition, the Office of Technology Assessment in a study, *World Petroleum Availability: 1980-2000,* did not find any evidence that a significant upturn in domestic production would occur.[2] In fact, OTA estimated a production rate of 5 to 8 MMB/D by 1990 and 4 to 7 MMB/D by 2000. Exxon's most recent energy outlook forecast domestic production of 7.1 MMB/D by 1990 and 7.8 MMB/D by 2000.[3] Thus, production rate estimates for the middle 1990's differ by as much as 7 MMB/D, an amount greater than current U.S. imports.

In OTA's judgment, the lower rates estimated in its study are still valid and it would be imprudent to assume otherwise in planning for the 1990's. The principal justification for these lower rate estimates is not so much an actual decline in total oil reserves as the increasing difficulty in extracting the oil that is found. The rate at which oil can be produced is declining because oil is no longer being found in the very large oilfields necessary to sustain or increase total production.

If domestic production does decline to 5 or 8 MMB/D by the mid-1990's, demand will have to decrease even faster than it has during the last few years just to keep imports at their current level. It is possible to greatly reduce petroleum product demand by both fuel switching and increased efficiency of use. This will require a substantial investment, however, and it is not clear yet whether it will be made. The current demand response is a combination of shortrun elasticity to the most recent price rise and the longer run elasticity—involving turnover of capital stock—to the 1973-74 price rise. Current forecasts of energy demand all show a continued, but slower, decline in petroleum demand for the rest of the 1980's but a steadying during the 1990's. In all cases, substantial imports will be necessary in the 1990's if the decline in domestic production assumed above takes place.

Faced with similar prospects after the 1973-74 oil embargo, Congress enacted a wide range of legislation to encourage a reduction of the Nation's dependence on oil imports. First, legislation was enacted to reduce petroleum demand. Foremost among these initiatives was the establishment in the Energy Policy and Conservation Act of the 1985 Corporate Average Fuel Efficiency (CAFE) standards for automobiles. More than half of total U.S. petroleum demand is in the transportation sector, which, in turn, uses about half of its petroleum in passenger vehicles. Other legislation to reduce petroleum demand included: 1) the Powerplant and Industrial Fuel Use Act, whose provisions require large combustors to convert from oil by 1990; and 2) systems of tax credits and financial programs to encourage capital investments for energy conservation in industry and buildings. Finally, legislation was passed to augment domestic supplies of petroleum substitutes through the production of synthetic fuels. The Energy Security Act of 1980 established the Synthetic Fuel Corp., with synfuel production goals of 0.5 MMB/D in 1987 and 2.0 MMB/D by 1992.

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[1] *Annual Report to Congress,* 1980, vol. 3, DOE/EIA-0173(80)/3, Energy Information Administration, U.S. Department of Energy, Washington, D. C., March 1981, p. 85.

[2] *World Petroleum Availability: 1980-2000—A Technical Memorandum* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1980), OTA-TM-E-5.

[3] *Energy Outlook: 1980-2000,* Exxon Co., U.S.A., Houston, Tex., December 1980, p. 7.

The efficacy of this approach is now being reevaluated, not only because of the time limitations of the legislation, but also in light of the price increases of 1979, which have caused the Nation to reduce imports more quickly than originally anticipated. The debate centers on whether the Government should continue its approach of the 1975-80 period—and if so which path or paths would be more effective—or whether the Nation can depend primarily on the current high oil cost —not entirely anticipated when the original legislation was passed—to reach an acceptably low level of oil imports. Complicating current debate is uncertainty about where oil prices will go in the immediate future. A steady decline in real prices over the next few years could substantially reduce market pressure toward increased conservation and development of alternative fuels, with the result that the Nation will be that much more economically vulnerable should there be dramatic upsurges in prices later in the decade or throughout the 1990's. Further, no matter which approach is preferable, general concern exists about the side effects of the Nation's movement to free itself from import dependence.

Of particular interest in the ongoing evaluation of policy are the approaches directed at producing synthetic liquid fuels and at reducing petroleum consumption by automobiles. These are by far the largest programs enacted by Congress, both in terms of their costs and of their effects on the economy.

In 1979, the Senate Committee on Commerce, Science, and Transportation requested OTA to assess and compare these two approaches to reducing oil imports. Because mandated increases in CAFE standards were to end in 1985, the committee was interested in whether further standards would be more or less effective than the synfuels program in reducing oil imports. The large increase in oil prices since 1979 and the response to this increase have changed the environment in which that request was made. As a result OTA has broadened its study to consider how far and fast automobile efficiency and synthetic fuels production can develop during the next 20 years, and to evaluate the effects on and risks to the industries involved. Such an evaluation is particularly important for the automobile industry because of its current precarious state. No matter what course the Nation chooses—continued regulation or more reliance on market mechanisms —the industry may be in for continued difficulties if the need for large capital investments continues while demand for automobiles remains relatively low.

In addition to assessing the import reducing potential of synfuels and increases in automobile fuel efficiency, this study also examines, although in considerably less detail, the oil savings that could be gained through fuel switching and conservation by stationary oil users. By combining the three approaches, plausible development scenarios for reductions in oil consumption are derived, leading to estimates for oil imports over the next 20 years.

The body of this report starts with an analysis of policy options that: 1) could influence the rate at which oil imports can be reduced or 2) affect the consequences of changes needed to reduce conventional oil consumption. The next chapter presents the major issues and findings of the report, including a discussion of the cost of oil imports, comparisons between increased automobile fuel efficiency and synfuels, and analyses of issues related solely to one or the other of these options.

The remaining chapters of the report contain the background analyses. Separate chapters on increased automobile fuel efficiency, synfuels, and stationary uses of petroleum present the technical and cost analyses for each. The final chapters analyze the economic and social effects and environmental, health, and safety impacts associated with both increased automobile fuel efficiency and synfuels, as well as the availability of water for synfuels development.

Chapter 3

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Chapter 3

Policy

INTRODUCTION

Success of any efforts to reduce oil imports will depend on many complex, unpredictable factors, including world oil prices, the success of technological developments, consumer behavior, general economic conditions, and—significantly—Government policies and programs.

Government policy is vitally important, because energy inevitably affects, whether directly or indirectly, all production and consumption decisions in an industrial society. How quickly and to what level the Nation displaces oil imports have direct implications for who benefits from, and who pays the costs of, energy independence. Such distributional questions arise regardless of policy choices. Thus, the policy choices made by Congress transcend a simple choice between intervention and nonintervention.

This chapter describes the policy issues and options for increasing automobile fuel efficiency and accelerating synthetic fuels development. (For a detailed discussion of policy options related to fuel switching and conservation in stationary uses of petroleum, and to biomass, the reader is referred to other OTA publications.[1]) The chapter addresses the circumstances which might justify direct Government intervention to displace oil imports. The well-established auto industry and the newly developing synfuels industry are then described; and those economywide and sector-specific characteristics which shape, direct, and pace each industry's ability to displace oil imports are identified. A brief, recent history of Government policy towards each industry is also provided. Finally, the major policy options available to Congress are discussed and evaluated based on the characteristics of the industries.

THE NATION'S ABILITY TO DISPLACE OIL IMPORTS

The three principal means for displacing oil imports—increased automobile fuel efficiency, synfuels production, and fuel switching and conservation in stationary uses—can all make important contributions to the Nation's energy future. Legislation has recently been enacted in all three areas to reduce conventional oil use, including the Energy Policy and Conservation Act of 1975, the Energy Security Act of 1980, the Fuel Use Act, and various taxes and credits to encourage capital investment for energy conservation in industries and buildings.[2] Some progress in displacing imports can be expected as a result of these Government programs working in concert with market forces.

OTA's technical analysis, presented in this report, concludes that if Congress wishes to eliminate net oil imports, significant accomplishment in all three areas may in fact be necessary to achieve this goal by 2000 if domestic production falls from 10 million to 7 million barrels per day (MMB/D) or less by 2000, as OTA expects.[3] In general, if there are no additional policies and programs, if technology developments are only partially successful, and if strong market forces for import displacement do not materialize, the United States can expect to import 4 to 5 MMB/D or more by 2000 (see issue on "How Quickly Can Oil Imports Be Reduced?" in ch. 4).

In the near future, Congress will face a number of decisions about whether to increase efforts to displace oil imports, and if so, at what speed imports should be displaced. Major decisions will concern the two major programs enacted by Congress: the setting of fuel efficiency (Corporate Average Fuel Economy (CAFE)) standards beyond the 1985 mandate for new cars sold in the United States, and the provision of large subsidies to promote rapid development of the synfuels industry. Such decisions will shape the future of both the auto and synfuels industries. Whether new policy initiatives are feasible, practical, and appropriate cannot be determined until Congress specifies the desired level and rate of import displacement. Is the goal to "eliminate" or to "reduce" imports?* Is this oil import displacement goal so vital to national interests that an emergency effort is required, regardless of any accompanying disruptions and dislocations?

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[1] *Energy From Biological Processes*, OTA-E-124, July 1980; *Residential Energy Conservation*, OTA-E-92, July 1979; *Dispersed Electric Energy Generation Systems*, OTA, forthcoming; *Energy Efficiency of Buildings in Cities*, OTA-E-168, March 1982.

[2] For details of recent legislation, see for example Congressional Quarterly, Inc., *Energy Policy*, 2d ed., March 1981.

[3] *World Petroleum Availability: 1980-2000—A Technical Memorandum*, OTA-TM-E-5 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1980).

Given the uncertainties, risks, and unpredictability associated with both the automobile fuel-efficiency and synfuels options, it is difficult to determine how far and in what direction present policies and market forces will take the Nation. OTA has not attempted to predict the detailed outcomes of alternative policy futures, but rather to demonstrate that the ability to displace oil depends on complex, interrelated factors, and to demonstrate that the Government's policy choices—whether to implement additional policies or to "do nothing"—will make a difference in the ability to achieve oil displacement goals. Policies are also identified that could be effective if future Government action is necessary.**

OTA's low estimate is that the average fleet fuel efficiency for new cars could reach at least 40 to 50 miles per gallon (mpg) by the early to mid-1990's and 45 to 60 mpg by 2000,*** based on relatively pessimistic expectations about how quickly improved automotive technology is deployed and purchased. Fleet fuel consumption for passenger cars would be about 2.1 MMB/D in 2000, for a cumulative savings of over 1 billion barrels of oil between 1985 and 2000 (assuming that the same proportion of large, medium, and small cars are sold in 2000 as are expected to be sold in 1985). The "high estimate" assumes that technology development is both successful and rapidly introduced into volume production. Average mpg ratings would be 55 to 65 mpg by 1995 and 60 to 80 mpg by 2000; and fleet fuel consumption for passenger cars could be as little as 1.3 MMB/D in 2000 for a cumulative savings of over 4 billion barrels (relative to a 30-mpg fleet and assuming a rapid shift to small cars).

However, the actual level of fuel consumption will depend on market demand for fuel-efficient cars and/or additional Government policies designed to facilitate either the manufacture or purchase of these cars. Although the low estimates are believed to be achievable in the absence of additional Government policies, they would be contingent on consumer expectations that the real price of gasoline will continue to increase. The high estimates are unlikely to be achieved in the absence of supporting Government policies unless a strong and continuing consumer demand for fuel efficiency is coupled with favorable technological progress.

OTA's estimates for a low- and a high-development scenario for synthetic fuels production depend principally on the price of conventional oil and the ease and rate with which synfuels processes are proven. A rapid buildup of the industry could begin as early as the late 1980's or as late as the mid-1990's, resulting in technically plausible production levels of fossil-synthetic transportation fuels of 0.3 to 0.7 MMB/D by 1990, 0.7 to 1.9 MMB/D by 1995, and 1 to 5 MMB/D by 2000.* In the absence of additional Government policies, the lower estimates are probably attainable but are contingent on a Government-supported commercialization program that reduces the high technical and associated financial risks to private investors of first generation plants.

Without a successful commercialization program, even the low estimates are probably unattainable. If there is a commercialization program, synfuels production **theoretically** could reach the high estimates without additional Government programs if: 1) early commercial-scale demonstration units are built and work successfully, and 2) synfuels production becomes unambiguously profitable. The maximum displacement of oil imports, however, would occur only if synfuels production concentrates on transportation fuels. It is OTA's judgment that, even with a commercialization program, the high estimates are likely to be delayed by as much as a decade unless policies tantamount to energy "war mobilization" are enacted.

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*"Elimination of oil imports" herein is assumed to mean the reduction of net oil imports to a level of about 0 to 1 MMB/D by 2000. At this level, the "security premium" for oil—the difference between the market price and full economic cost to the Nation of oil imports—would approach zero. This level of supplies could be procured primarily from the United Kingdom, Canada, and Mexico; and foreign producers generally would be forced to compete for markets. Because of the "security premium," policy decisions about the value of displacing imports should not be based solely on the international price of oil.

**An examination of Government policy related to the use of petroleum in the stationary sector is beyond the scope of this report. A summary of the major policy options for the stationary sector, however, is found in app. 3A to this chapter.

***Earlier trends showing relatively strong demand for fuel economy have encouraged some domestic manufacturers to predict new-car fuel economy averages of over 30 mpg by 1985 (the 1985 CAFE standard requires a fleet average of 27.5 mpg), while individual vehicles already on the market exceed 45 mpg.

*These estimates exclude contributions from biomass.

Fuel switching and conservation of oil in stationary uses will also be extremely important for displacing oil imports and would complement both fuel-efficiency and synfuels efforts. Although much of the potential for displacement could probably be achieved by market forces by 2000 (under the high oil price scenario of the Energy Information Administration (EIA)),[4] additional policies to encourage fuel switching and conservation will likely be required to accelerate the changes or completely eliminate stationary fuel oil use. The level of displacement that can be obtained depends not only on future oil prices, but on financing, regulation, and technical factors. Efficiency increases in the various nonautomobile transportation uses could also be significant.

Displacing oil imports is a necessary but not a sufficient condition for achieving national energy security. Such security translates into an essential self-reliance, availability, affordability, and sustainability of energy resources. Alternative energy sources may present their own set of supply and/or distribution problems. Furthermore, the relationship between the level of imports and the level of insecurity is not proportional in an obvious way. Even if the Nation could eliminate all of its oil imports, U.S. energy security could still be seriously affected if interruptions in world oil supplies threatened international commitments with allies, imbalances in the world monetary system, and pressures on foreign exchange markets. Thus, efforts to displace the Nation's most insecure oil resources—its imports—should not divert attention away from ensuring the resilience of the alternatives chosen and thus the stability of both domestic and international energy systems.

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[4] Department of Energy, Energy Information Adminstration, *Annual Report to Congress,* vol. III, May 1982.

RATIONALE FOR A DIRECT FEDERAL ROLE

The basic rationale for direct Federal involvement in a market economy is that—in limited but important areas—market prices and costs used to evaluate returns on private investments do not reflect the full value and cost of the investments to society as a whole. National security and environmental protection are classic examples of values and costs that are not reflected in profit and loss statements. Private calculation of profits also causes market mechanisms to be most responsive to short-term economic forces as opposed to long-term social and economic goals.

The three principal reasons for such market "failures" are that: 1) some of the social benefits are public and not private goods, 2) some of the costs are not paid by the private sector, and 3) costs and benefits are not fully known. All three situations arise in the context of displacing oil imports in general and of both increasing automobile fuel efficiency and producing synfuels in particular. The inability of the conventional marketplace to ensure the effective and rapid displacement of oil imports has major implications for the Federal role, depending on the goals chosen and the resources made available.

National security is a public good that has traditionally received Government support. National energy security, promoted by the displacement of oil imports, is an important component of overall security. Direct Government involvement would thus be justified if market forces alone were not believed capable of achieving the quantity and rate of oil displacement required by national security goals. The value to the Nation of accelerating automobile fuel efficiency increases and synfuels production would be in addition to any private returns to investment.

Both increased automotive fuel efficiency and synfuels production give rise to side effects and tradeoffs; those who benefit from the investments are not necessarily the ones who bear the full costs. Side effects can fall on different sectors of the economy, regions, or consumer groups depending on the investments chosen. In the case of increased automobile fuel efficiency, the rationale for Government policy is that the activities stimulated by market forces alone do not provide, for example, adequate safety and employment safeguards. There are other possible tradeoffs, on the one hand, between improving the competitive position of the U.S. auto industry by encouraging investments in increased auto fuel efficiency, and, on the other hand, possible declines in auto-related employment levels (because of increased automation, contraction of the domestic industry), increased consumer costs, and decreased safety. With respect to synfuels, Government intervention could be similarly warranted if market decisions do not reflect environmental, health, safety, and other social concerns.

Both increased automobile fuel efficiency and synfuels production are characterized by financial risks and uncertainties. If market forces alone determine outputs, investments associated with these alternatives might be delayed or canceled. In such cases, the Government could choose either to assume some of the risk or to help reduce components of uncertainty. The auto industry's uncertainty focuses on unpredictable consumer demand for fuel-efficient cars, the long leadtimes for investments, and, to a lesser degree, on the rate of technological development. Synfuels production is subject to significant technological uncertainties and, in turn, financial risks. Both the auto and synfuels industries are also affected by uncertain and as yet undetermined future Government policies.

DISTINGUISHING FEATURES OF INCREASING AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS PRODUCTION

The major forces that will shape, direct, and pace increases in automobile fuel efficiency and synfuels production are summarized in table 7. Identifying these forces may indicate both the potential opportunities for and limitations of Government policies in achieving a desired level and rate of import displacement, and the appropriateness, practicality, and desirability of specific policies or combinations of policies.

Although increased automobile fuel efficiency and synfuels production share several attributes, essential differences between them suggest that there is no single role for Government policies and programs. These two options should be viewed as complementary measures for reducing oil imports. Each option has different implications for the rate of oil import displacement and will give rise to different types of economic and noneconomic impacts on the Nation. In addition, within the uncertainty about investment costs (per barrel per day oil equivalent (B/DOE) produced or saved), neither increased automobile fuel efficiency nor synfuels production appears to have an overall unambiguous enconomic advantage over the other. For this reason, the nonmonetary and often nonquantifiable differences between these options will be the principal means for distinguishing between them for policymaking purposes.

The factors that determine the rate of fuel switching and conservation in stationary applications will share some common elements with automobile fuel efficiency increases and synfuels production. The success of fuel switching will depend critically on the efficiency of stationary energy uses, the technologies for producing natural gas from unconventional sources, the supply and future price of conventional natural gas, and the ability of the utility industry to solve its current financial problems. In the absence of mandated conservation or performance standards, conservation measures will depend primar-

Table 7.—Distinguishing Features of Increasing Automobile Fuel Efficiency and Synfuels Production

Increasing automobile fuel efficiency	Synfuels production
1. Both near- and long-term restructuring of an existing industry	1. Growth and promotion of a new industry
2. Dominated by a few large, mature companies	2. Likely to be dominated by a few large, mature companies
3. Automobiles as consumer durables; differentiable; deferrable	3. Synfuels as uniform, consumable commodities
4. New technology involved, but can proceed incrementally; associated risks are an ongoing feature of industry	4. Large technical risks; possibilities for "white elephants," major risk occurs with first commercial-scale demonstration plants
5. Industry must produce competitive products each year, including fuel-efficient cars	5. Sponsoring industry is involved in a breadth of activities that provides alternative investment and business opportunities, of which synfuels is one
6. Precariousness of industry's current financial position; need to ease readjustment of an industry in distress	6. Soundness of sponsoring industry's current financial position; need to facilitate growth
7. Large demand uncertainty	7. No unusual demand risk except insofar as synfuels differ from conventional fuels
8. Dispersion of industrial activities, domestically and, increasingly, internationally; some concentration of activities in the North-Central region of the United States	8. Dispersion of activities among coal regions; current oil shale activity concentrated in a small area of the West
9. Capital intensity and associated risks	9. Capital intensity and associated risks
10. Declining profit margins in domestic industry	10. Potential for profit still highly uncertain
11. Significance of international competition (i.e., auto imports); importance of domestic market to financial viability	11. Long-term export potential; importance of international competition (i.e., oil imports) in terms of establishing the marginal price
12. Large amounts of capital continually required for redesign, retooling, etc.; final costs for improved fuel efficiency uncertain; calculation of capital costs for fuel economy dependent on methods for cost allocation	12. Large amounts of capital required primarily in the initial construction phase; final costs for synfuels production uncertain
13. Can make significant contributions to reducing U.S. oil imports; contributions have a long leadtime but can have significance incrementally	13. Can make significant contributions to reducing U.S. oil imports; contributions have a long leadtime and will not be significant until commercialization
14. Caters to a saturated market; focus on product replacement rather than growth markets	14. Caters to a slowly growing or possibly declining market
15. Consumer costs are investment to reduce future fuel purchases	15. No investment needed by consumer; consumer pays incrementally for each increment of consumption
16. Reduces consumption of fuel	16. Substitutes one fuel for another
17. Fuel savings in automobiles limited to about 3.5 MMB/D with about 1.5 MMB/D savings coming from achieving a 30-mpg fleet	17. Fuel-replacement potential ultimately limited by demand for synfuels, environmental impacts of synfuels plants, and coal and oil shale reserves
18. Principal health impact may be increased auto deaths due to smaller cars	18. Environmental and health impacts from: large-scale mining of coal and oil shale; possible escape of toxic substances from synfuels reactors (major risks are direct worker exposures, contamination of ground water); visibility degradation; development pressures on fragile, arid ecosystems

SOURCE: Office of Technology Assessment.

ily on investor behavior. Although there are few technical constraints, there are technical uncertainties about the conservation potential of buildings and the success of particular conservation investments. Both fuel switching and conservation are difficult to put into practice because the measures are varied, site-specific, and in some cases costly.

Factors Affecting the Rate of Automobile Fuel-Efficiency Increases

In order to be internationally competitive, the domestic automobile industry is currently undergoing major structural adjustments.[5] This readjustment is the consequence of two interrelated forces. First, the domestic industry is undergoing a long-term restructuring that is being experienced by auto manufacturers worldwide. Resource pressures and a trend towards small, fuel-efficient, and standardized "world cars" have resulted in a period of corporate consolidation, with firms being more closely tied by joint design and/or production ventures, and a geographic dispersion of product assembly. Secondly, U.S. auto manufacturers are uniquely faced with a series of short-term problems that arise because they have historically served a market that demanded large, relatively fuel-inefficient cars. U.S. manufacturers have been the principal producers (and promoters) of large cars and have historically earned their greatest profit margins on these cars.

The strains placed on the domestic industry, as it redesigns its products and retools its facilities for fuel efficiency in the near and midterm,[6] are the forces that could most appropriately be targeted and eased by Government policies. In addition, because of the size and dispersion of the U.S. auto industry throughout the national economy, maintaining the health of the industry and minimizing the side effects on both upstream activities (e.g., dealers, suppliers), and downstream activities (e.g., consumers) are of potentially great Government concern.

Some aspects of the domestic industry's short-term readjustment problems are caused by economywide factors such as rising energy prices, tight credit, and high interest rates. These factors have affected both manufacturers—by making capital scarce and expensive—and consumers, who (with approximately two-thirds of all purchases historically being on credit) are deferring purchases.

The market changes associated with high gasoline prices and the threat of gasoline shortages experienced in the 1970's have shown that consumer demand is the most powerful influence on the rate and manner of fuel-efficiency increases. However, the prices consumers will pay, and the tradeoffs consumers will accept in vehicle attributes—of which fuel efficiency is only one—are highly uncertain and ambiguous. For example, in the mid-1970's, and again in 1980-81, the proportion of relatively small cars purchased to large cars purchased decreased.* Furthermore, consumers did not consistently buy the most fuel-efficient car in a given size class. The ability of the industry to sell cars is made additionally difficult because there has been a steady slowing in the total demand for automobiles due to stagnant per capita disposable income and a general aging of the population, implying that the industry is mainly serving a domestic replacement rather than growth market. And at the same time, imports have captured an increasing share of the domestic market.

The need to make large investments under conditions of uncertain demand for fuel efficiency and slowing overall demand for automobiles, aggravated by economywide stresses, is the most significant contributor to the financially precarious position now facing the domestic auto industry. Losses to U.S. auto manufacturers exceeded $4 billion in 1980. As sales have decreased, profits have declined, and the industry's longstanding ability to reinvest with internally generated funds has decreased. Because the industry is capital-intensive, any underutilization of capacity also implies large costs. Large amounts of outside capital will be required to retool for increasing fuel economy. If companies are forced to cut back on their capital investment programs in the near term (as some are doing), they will not only forestall fuel-efficiency improvements but may also become increasingly vulnerable to foreign competition.[7]

In adjusting to this, U.S. manufacturers face a series of complex decisions. Domestic manufacturers' weak competitive position is primarily due to high production costs relative to foreign producers[8] and consumers' perceptions of value in domestic v. imported cars, that are difficult to quantify. If a strong demand for fuel efficiency develops, rapidly increasing the fuel efficiency of domestic automobiles could help to sell them. Demand for fuel efficiency, however, is usually accompanied by a shift in demand to smaller cars, the market area where U.S. manufacturers have been least competitive with imports. This shift would therefore also require that domestic manufacturers devote some of their investments to changes unrelated or only partially related to fuel efficiency. Corporate strategy, the way complex investment decisions are handled, overall demand for new cars, and the demand for fuel efficiency vis-a-vis other attributes of automobiles will all interact in a complex way to affect the actual rate at which fuel efficiency increases.

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[5] See also *U.S. Industrial Competitiveness—A Comparison of Steel, Electronics, and Automobiles*, OTA-ISC-135 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, July 1981).

[6] See General Accounting Office, "Producing More Fuel-Efficient Automobiles: A Costly Proposition," CED-82-14, Jan. 19, 1982.

*These data include both domestically produced and imported cars.

[7] *U.S. Industrial Competitiveness*, op. cit.

Technological uncertainties will also figure in determining fuel efficiencies actually achieved. These uncertainties relate to the behavior of various elements of the vehicle system, the way in which these elements are integrated and possible performance tradeoffs among elements, and the cost of specific manufacturing techniques. The rate of product and process development, and particularly the success of the development efforts (by no means assured) will influence the extent of fuel-efficiency increases. Basic research could lead to additional fuel economy gains by providing a better understanding of some of the complex processes related to fuel consumption (e.g., nonsteady-state combustion).

The single most important factor limiting the development of electric vehicles (EVs) is battery technology. Even if EVs were to become practical, however, they would not have the potential to displace significant amounts of imported oil, primarily because they would be substitutes for the most fuel-efficient gasoline or diesel-powered cars. The Government could justify accelerating the development and introduction of EVs if the goal is to reduce automobile pollution in the inner cities or to promote a transportation mode that does not use petroleum. EVs are petroleum independent except insofar as electricity is generated from oil.

Automobile Fuel Efficiency—Policy Background

The industry has been regulated by Government policies and programs primarily since the 1960's. Worker and public health and safety aspects are regulated by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration; product safety and emissions by the National Highway Traffic Safety Administration (NHTSA) and EPA. Auto sales are affected by all policies that influence consumer demand. In the aftermath of the 1973-74 oil embargo, the Government became actively interested in promoting automobile fuel efficiency, and legislation was subsequently enacted to reduce U.S. dependence on oil imports.

Policy for increasing automobile fuel efficiency is embodied principally in two programs.* The principal policy instrument for increasing fuel efficiency was established by the 1975 Energy Policy and Conservation Act (EPCA) and specifies CAFE (i.e., fleet) standards for new cars and light trucks between the model years 1978 and 1985. Provisions of the CAFE program have generally tried to recognize the financial difficulties of the auto industry. CAFE standards mandate that new-car fuel efficiency will double, incrementally, between the early 1970's and the mid-1980's. (American-made cars had averaged about 14 mpg over the period 1965-75; the 1985 CAFE standards require fleet averages of 27.5 mpg and are to remain in force after 1985.**) Subsequent provisions in the Fuel Efficiency Act of 1980 eased the compliance requirements of the CAFE program, but the basic efficiency standards remain in force. Possible alteration of the standards set by the program for post-1985 could be a major policy issue coming before Congress.

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[8] The sources and magnitude of these cost advantages are not well understood. Understanding the nature of any cost advantages enjoyed by competitors will be critical for determining how, when, and if U.S. manufacturers can get their cost structure into line. See *U.S. Industrial Competitiveness*, op. cit., pp. 96-99.

*A third program was enactment of the 55-mph speed limit.

**The Energy Policy and Conservation Act provided guidelines for the Department of Transportation to set standards for the early 1980's; Congress set standards for 1978 and 1985.

The second major program, part of the 1978 National Energy Act, establishes excise taxes for purchases of automobiles with low fuel-economy ratings beginning in the model year 1980. Current "gas-guzzler" taxes range from $200 for cars rated at 14 to 15 mpg in model year 1980 up to $3,850 for specialty cars rated under 12.5 mpg beginning in model year 1986. Such taxes raised only $1.7 million in fiscal 1980.[9]

OTA's analysis indicates large uncertainties in both economic and noneconomic costs of fuel-economy increases. OTA has also identified uncertainties in demand for fuel-efficient cars as critical to increasing fuel efficiency. These uncertainties, together with the desire of domestic manufacturers to serve a wide variety of consumer tastes with a limited level of capital investment, are mainly responsible for the industry's reluctance to accelerate the development and introduction of fuel-efficiency increases. Until fuel efficiency is a—or perhaps the—major selling point for new car buyers, this reluctance, understandably, is likely to continue.

Factors Affecting the Rate of Synthetic Fuels Production

Unlike increasing automobile fuel efficiency, which may entail restructuring a major existing U.S. industry, production of synthetic fuels involves the emergence of a major new industry.* The costs and therefore the profitability of producing synfuels are influenced by major uncertainties that both characterize the economy as a whole and are specific to the synfuels industry. At the economywide level, factors such as the price of oil, the cost of capital, inflation in general and hyperinflation in the construction industries, and the availability of appropriate labor and materials will determine the financial risks that must be assumed by investors. Like the auto industry, the synfuels industry is capital-intensive. A moderately sized (50,000 B/DOE) fossil synfuels plant could require an investment of $2 billion to $5 billion; the industry's growth and ability to attract capital will thus be highly sensitive to the investment climate.

The major constraint on the development of a synfuels industry is the technical uncertainty associated with synfuels processes. There is essentially no domestic commercial experience with synfuels processes, and processes and design concepts have not yet been adequately demonstrated at a commercial scale. It is thus conceivable that design errors and unexpected operational problems could delay construction or cause a completed facility to be inefficient, even a "white elephant" operating at only a fraction of its capacity or at greatly higher cost than anticipated. As with any capital-intensive industry, there are high costs associated with the underutilization of capacity.

Synfuels production will be an attractive investment if investors view the technical risks as being low (i.e., commercial-scale demonstration units are successful) and they expect oil prices to rise sharply in the future, or if they want to secure an early market share in case synfuels do become competitive with the oil market. Unless oil prices rise more rapidly than synfuel construction costs, however, synfuels plants may not be economically attractive even after the processes are proven and the technical risk is small.

Synthetic Fuels Production—Policy Background

Congress created the National Synfuels Production Program (NSPP) under the Energy Security Act of 1980 (ESA) to promote the rapid development of a major synfuels production capability. Specific goals are set for 500,000 B/DOE by 1987 and 2 MMB/DOE by 1992.[10]

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[9] Congress rejected 60 proposals to tax purchases of inefficient new cars and 19 proposals to raise gasoline taxes between 1973 and 1977. In 1977, President Carter proposed a stringent "gas guzzler" tax keyed to CAFE standards which included a rebate program for purchases of especially efficient cars (which Congress decided would violate the General Agreement on Tariffs and Trade—or GATT). When the current excise taxes were enacted, critics argued that they would save only 10,000 bbl/d of imported oil, while the Carter proposal, with higher taxes applied to more vehicles, was estimated to be able to save 170,000 bbl/d (*New York Times,* Dec. 10, 1978).

*The liquid and gaseous fuel industry may also undergo a restructuring, however. Synfuels development will tie up capital in considerably larger blocks and for longer periods than historically experienced by the industry. A concentration of ownership is also likely.

[10] Synthetic substitutes for petroleum and natural gas are the focus of the NSPP; other programs support development of synthetic fuels from biomass. Biomass subsidy options have been reviewed in detail in the Office of Technology Assessment's *Energy From Biological Processes.* For the NSPP definition of synfuels see Public Law 96-294, sec. 112 (17) (A).

In the first of three phases, the Department of Energy (DOE) was authorized to offer financial incentives for the production of alternative or synthetic fuels. The original authorizing legislation (Public Law 96-126) made about $2.2 billion available, mainly for purchase commitments or price guarantees pursuant to the provisions of the Federal Nonnuclear Research and Development Act of 1974; total funds were subsequently increased to approximately $5.5 billion.[11]

ESA created the Synthetic Fuels Corp. (SFC) in the second phase as a quasi-investment bank, to provide incentives to promote private ownership and operation of synfuels projects. SFC is backed by funds deposited in a special Energy Security Reserve in the U.S. Treasury and to be used for financial assistance in the form of: 1) price guarantees, purchase agreements, and loan guarantees; 2) direct loans; and 3) support to joint ventures.* The governing board of SFC can decide which DOE projects it will take over once the board becomes fully operational. Total funds authorized for SFC are approximately $17 billion through June 30, 1984.[12]

The third phase of the NSPP is to begin in mid-1984, at which time Congress may appropriate an additional $68 billion on the basis of a comprehensive synfuels development strategy to be submitted by the SFC board. SFC is scheduled to lose the authority to make awards in 1992 and to be terminated in 1997. Some revision of NSPP dates, goals, and/or financing may have to be made if the production of synfuels falls short of the original NSPP goals—as is expected. In OTA's judgment, Congress is unlikely to have sufficient information by 1984 about the technical aspects of synfuels processes to be able to make long-term synfuels decisions.

SFC has received continued political support, and the administration is committed to ensuring the development of a commercial synfuels industry, as announced in its *A Plan for Economic Recovery* (February 1981). In addition DOE has committed about 50 percent of its approximately $5.5 billion, and provisional commitments have been made to two projects.*

Reflecting a recent major policy change however, Government support is now to emphasize long-range, high-risk research and development (R&D) activities that are unlikely to receive private sponsorship. This shift is likely to have different effects on the two main types of synfuels projects: 1) projects designed to test and demonstrate alternative design concepts, learn more about the details of the processes involved, and gain operating experience (demonstration plants); and 2) projects designed to demonstrate commercial-scale process units (CSPUs).

Demonstration plants are generally smaller than commercial-scale plants and are not intended to earn a profit. Under the new policies, DOE programs to support demonstration plants are being terminated, but these projects presumably can apply to SFC for support.

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[11] This figure does not include an additional $1.27 billion that has been made available for biomass energy, including alcohol fuels and energy from municipal waste. For further details on this legislation, see Public Law 96-294, Public Law 96-304, and the CRS issue brief (No. MB70245) "Synthetic Fuels Corporation, Policy and Technology," by Paul Rothberg.

During the interim program, DOE awarded, in a first "round," $200 million of these funds, half each for feasibility studies and for cooperative agreements. Of the first $200 million, approximately two-fifths, or $80 million were for biomass projects, while the remainder went to synfuels activities. DOE has in past years also provided support for a variety of research and demonstration activities to support synfuels development.

DOE originally planned a second "round" of awards for feasibility studies and cooperative agreements, but at the request of the Reagan administration the $300 million authorized for these awards was rescinded as an economy measure.

*In its guidelines to investors, SFC indicates that it strongly favors price guarantees, purchase agreements, and loan guarantees, which emphasize "contingent liabilities." The cost to the Government of such aid varies with the success of the assisted projects; it is minimized when projects produce synfuels that can be priced competitively with other fuels. To prevent overconcentrating funds, SFC can give no project or person more than 15 percent of its authorized funds, which is about $3 billion during its early years (1981-84). In the case of loan guarantees, SFC cannot assume a financial liability for more than 75 percent of the initial estimated cost of the project, requiring the assisted company or companies to risk a sizable amount of their own funds. Although there are broad guidelines, the terms of each award will be negotiated separately with project sponsors.

None of the contingent liability incentives available to SFC can exceed the amounts held for SFC in the U.S. Treasury; that is, SFC cannot "leverage" its funds by guaranteeing loans in excess of its actual reserves. In the period since the passage of the synfuels legislation, estimates of the cost of commercial-scale synfuels plants have continued to increase; therefore, unless investors are willing to negotiate guarantees for smaller percentages of project costs than allowed by legislation, the amount of synfuels produced by the subsidy program may be much smaller than originally anticipated.

[12] Synthetic Fuels Corp., "Assisting the Development of Synthetic Fuels," p. 1. The $17-billion figure is an approximation. SFC is authorized to spend up to $20 billion, but the money obligated in the interim program is to be substracted from the larger figure.

*These are a loan guarantee of up to $1.5 billion to the Great Plains Coal Gasification plant in North Dakota and an as yet unnegotiated assistance agreement with the Union Oil Co. oil shale project (product purchase guarantee).

If CSPUs can be made to operate properly, several such units might be built and operated in parallel in a commercial synfuels plant. Because the process unit is intended to be part of a commercial synfuels plant, support for CSPU demonstrations continues to be available through SFC, under the new administration policies.

Termination of DOE support may lead to cancellation of several demonstration plants, since they must now compete against more developed technologies for SFC support.* This would result in a poorer understanding of various synfuels processes and a narrower range of technology options available to potential investors. It could also reduce the prospects for commercializing plants capable of producing fuels from a variety of coals found in different regions of the country.[13] Finally, processes with the greatest immediate (i.e., not necessarily long-term) commercial promise are likely to be favored by SFC in order to meet production targets.*

Although every commercial-scale process will have gone through a demonstration plant stage, the design of the CSPU will also be based on numerous other sources of relevant information. Terminating demonstration plant projects will reduce this pool of information, thereby increasing the risks that CSPUs will not function properly and reducing the design options for correcting malfunctions. Development of promising longer term synfuels processes may also be delayed or overlooked entirely. For these reasons, it is OTA's judgment that DOE's termination of support for demonstration plants is likely to reduce the rate at which a synfuels industry is built.

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*Apparently as a result of reduced Government interest in directly promoting synfuels, three projects previously supported by DOE have been canceled (SRC II and two high-Btu gasification projects, the Illinois Coal Gasification Project and the CONOCO Project in Noble County, Ohio). Four additional demonstration projects are continuing with reduced levels of DOE support and their futures are in doubt: H-Coal, EDS, Memphis Medium-Btu, and SRC I. At least one upcoming project, not yet at the demonstration stage, has also been canceled in light of recent developments (a low-Btu Combustion Engineering project).

[13] See Paul Rothberg, "Coal Gasification and Liquefaction," CRS issue brief No. IB77105, Aug. 12, 1981.

*Legislation calls for SFC to consider a wide range of alternative synfuels technologies in order to broaden industry's experience with the technical and economic characteristics of many processes. This requirement may conflict with the mandate to meet production targets—targets that already appear unrealistic.

POLICY OPTIONS

This section evaluates the major policy options available for displacing oil imports generally and specifically for stimulating auto fuel-efficiency increases and synthetic fuels production. The evaluation is based on the industry characteristics so far discussed and on the technical analysis which appears later in this report. In particular, the impacts of several policy options that have recently received congressional attention are estimated. Note, however, that policies are not discussed in the context of emergency oil shortfalls.

The policy choices available to Congress differ along several key dimensions: 1) the rate and degree of oil import displacement; 2) the degree and specificity of Government intervention and budgetary effects; 3) the types, magnitude, and distribution of benefits and costs; 4) implications for the long-term, sustainable, and competitive health of the affected industries; 5) the relationship of the choices to other Government programs; and 6) the feasibility of future actions. The selection of policy instruments and resulting tradeoffs will reflect the priority ascribed to each dimension. Policies can generally be designed either as incentives or penalties, incentives more closely approximating the conventional marketplace. Policies can be directed at either economywide or sector-specific measures.

Economywide Level.—"Economywide" policy choices are concerned with overall economic and business conditions—as measured by such indicators as inflation, unemployment, and interest rates—that determine the financial health, investment climate, and productive capabilities of U.S. industries. Fiscal and monetary policies are the primary instruments in this category; other measures could promote innovation, regulatory reform, technology development, and human resources development. Such Government policies generally seek either to remove or to reduce impediments to a strong and stable economy, as well as to raise business and consumer confidence in the face of changing economic conditions. The advantage of such policies is that they can be directed at many industries, although they will have different impacts on the various affected industries. They are most commonly preferred as a complement to market forces, because their scope enables them to enlist the broadest base of support, and they are best equipped for integrating a wide range of economic and social objectives. General economic policy, however, has only limited ability to promote the displacement of oil imports and to stimulate specific actions, and may indirectly distort capital flows among oil displacement alternatives.

Automobile fuel efficiency and synfuels production (as well as fuel switching and conservation in stationary applications) are influenced by such economywide factors as high interest rates, tight credit, increasing resource costs, and changes in real disposable income. As for the auto industry, general economic conditions influence the ability of consumers to buy cars and the ability of manufacturers and suppliers to invest in needed changes. General economic policy could help to stimulate demand for automobiles by lowering the costs of consumer credit and by making credit available. Strong demand for new cars, together with stimuli that reduce the effective costs of capital and retooling can, in turn, stimulate the supply of fuel-efficient automobiles.

Economywide measures, however, would not induce consumers to buy domestically manufactured vehicles rather than imports; and they could have a mixed effect on local automobile production and employment. Economywide measures may facilitate investments by foreign firms in U.S. facilities, but they also assist investments by local producers in labor-saving equipment and investments by domestic manufacturers in low-cost production facilities abroad. These investments may ensure the financial health of individual, American-owned firms, but attendant reductions in domestic employment may aggravate regional economic problems.

Deployment of synfuels production capacity will also be sensitive to general economic conditions: interest rates not only influence the availability of capital for building plants; the capital costs also help determine whether products can be priced competitively. Once established, however, the synfuels industry is expected to be relatively insensitive to general economic conditions to the extent that synfuels are indistinguishable from conventional fuels and are competitively priced, and the plants do not require frequent retooling. Based on the analysis provided in this report, it is OTA's judgment that favorable economywide conditions, by themselves, are still unlikely to provide sufficient incentive for private firms and investors to accelerate the commercialization of a synfuels industry because of the large technical risks associated with as yet commercially unproven synfuels processes.

Sector-Specific Level.—Policies can be aimed at specific industries to stimulate industrial competitiveness, ease the adjustment of firms to new economic conditions (rapid growth, short-term distress, or long-term decline), or to promote the achievement of national or regional objectives (e.g., national security, regional development). To formulate policies at this level, analyses of individual sectors and linkages among sectors are essential. The major disadvantages of such policies are that they do not always address the underlying causes of market distortions and they discriminate against other industries which are not similarly assisted. In terms of the auto industry, sector-specific policies would be most effective if they addressed the market risk, which is a major factor determining the rate of fuel-economy improvements. The major constraint on rapid deployment of a synthetic fuels industry is technical uncertainty with respect to unproven processes and, currently, the cost of conventional oil products.

Economywide Taxation—Oil and Transportation Fuels

General taxation measures are one vehicle for stimulating capital investment across the economy. Economywide taxation measures that specifically relate to displacing oil imports are taxes on oil imports, on oil in general, and on transportation fuels (e.g., gasoline and diesel fuel) in particular. To the extent that the Nation's energy "problem" is defined as dependence on insecure foreign sources, an oil or transportation fuel tax would promote security by reducing oil demand. However, an oil or gasoline tax could be counterproductive to the degree that the energy "problem" is defined as a lack of relatively low-cost, high-quality fuels. Consumers may oppose an oil import tax, even though its impact would be minor compared with that of large OPEC price increases, as was the case when an oil import tax of $0.33/bbl was in effect briefly during the Ford adminstration. Its impact, if any, was minor in comparison with that of OPEC's hikes.

Oil taxes can be imposed either on oil generally or on oil imports in particular. The advantages of an oil tax arise because of three features. First, the tax would make all uses of oil more expensive without prejudging which kinds of adjustments would be most desirable. A general tax on oil would thus reduce consumption and, in turn, imports. Second, the tax could be designed to isolate consumer oil prices from reductions in international oil prices. For example, if OPEC prices remain steady through 1984 and if inflation continues at current rates, the real price of oil could decline by as much as 20 to 30 percent during this period. While perhaps beneficial to consumers in the short term, declining real prices for petroleum products would probably lead to increased petroleum demand. Consistent price signals would also provide assurance both to the auto industry that demand for fuel-efficient cars would be at least sustained if not increased, and to synfuels developers that they would receive at least a constant real price for their products. Finally, tax revenues could be used, for example, to support import displacement investments, or to offset some of the potential adverse effects of the tax (e.g., to fund income support programs).

Taxing only crude oil, however, and not its products could reduce the international competitiveness of industries heavily dependent on oil—such as refineries and petrochemical companies.[*] Furthermore, because oil taxes do not differentiate among industries that use oil, they are not effective means of altering the competitive position of either automobile fuel economy or synfuels production relative to any other method for displacing imports (if such alteration is desired). Such taxes could also contribute to inflation generally and would be paid for disproportionately by consumers with low incomes. Compensatory programs and payments could deal with such side effects, but at additional implementation and administrative expense.

Taxes targeted at only oil imports could discriminate against companies, and regions of the country, that are heavily dependent on imported oil. It is more likely, however, that import taxes would cause the general price of oil to increase to a level close to the price of taxed imports. Any general price increase, in turn, would create additional revenues for domestic petroleum producers. The total revenues generated by an import tax would thus be only partially received by the Government. Compared with a general oil tax, an import tax is thus likely to result in a smaller fraction of revenues being available to the Government for additional import displacement measures or to offset any adverse impacts of higher oil prices. The windfall profits tax captures some additional revenue, but is more complex to administer than a general tax on all oil.

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[*] It is possible that refining activities would relocate overseas unless additional import restrictions were also imposed. With respect to synfuels production, refiners might be able to cut profit margins and continue to process and sell oil at prices below synfuels prices in order to maintain refining volumes (which are already rather low). Because many old refineries do not have capital charges, refining costs would be dominated by the variable costs of about 15 to 20¢/gal of product plus the oil acquisition costs. Consequently, taxes may have to raise the cost of imported oil to within about $6/bbl of synfuel product (15¢/gal of gasoline equivalent) to ensure that the refiners cannot economically use oil imports as competitors for synfuels. This would directly harm some companies engaged in oil refining, but this may be a necessary tradeoff to ensure that synfuels actually displace imported oil, rather than act to reduce domestic petroleum product prices and thereby discourage a reduction in domestic oil consumption.

Another disadvantage of an import tax, frequently discussed, is the possibility that oil exporting nations might see the acceptance of added cost by U.S. users as an indication that their crude prices could be further increased without reprisal or economic hardship. This objection probably is not valid, however, during times of crude oil surplus in the producing nations.

With respect to transportation fuel consumption, a tax either on oil or on transportation fuels reduces demand for all uses of transportation fuel, including automobile travel, as well as increasing the relative demand for fuel efficiency. It could reduce new-car sales, however, and could also reduce the profitability of truck transports, agriculture, airlines, tourism, and other fuel-dependent industries. Taxes on only gasoline would avoid some of these problems, but they could encourage the purchase of diesel-fueled automobiles.

Gasoline taxes in this country have increased only slightly during the past two decades.[14] The Federal tax has been $0.04/gal since 1960, while the average State tax has increased from $0.065 to $0.08/gal. A gasoline tax that increased the price of gasoline by, say $0.05/gal (i.e., a 3-percent increase over a $1.50 price) would raise about $5 billion per year at current consumption rates, as would a $1.00/bbl crude oil tax. In order to offset inflation since 1960, the current gasoline tax would have to increase by about $0.15/gal. Taxes on gasoline are significantly lower in the United States than abroad.*

The ultimate effect an oil, gasoline, or diesel fuel tax would have in displacing oil imports depends on at least three factors. First, the effectiveness of the tax in the long run depends on the actual purchase and use of fuel-efficient vehicles. Estimates of the responsiveness of demand (its "elasticity") to changes in gasoline, auto, and other prices vary widely from study to study, but they suggest that a tax on crude oil or transportation fuels would have to be relatively large to motivate consumers to trade in their relatively inefficient cars for more efficient ones.[15] Note, however, that tax provisions per se would not differentiate between domestic and foreign manufacturers except insofar as one produces more fuel-efficient vehicles.

Secondly, tax impacts will depend on final oil or fuel prices. The entire tax amount need not be passed on to consumers if producers are able to maximize profits by lowering the price of gasoline, absorbing part of the tax, and increasing sales. As long as demand for oil is slack relative to supply, at least part of the tax will be absorbed by producers.

Finally, the effect of taxes will depend on the degree to which driving is reduced. While OTA's analysis of oil savings attributable to fuel economy improvement assumes a steady increase in vehicle miles traveled (VMT) (but a drop in VMT per capita), lower total VMT induced by high gasoline prices would increase actual oil savings.* However, this could also reduce car sales.

While gasoline stations and refineries would be affected by reduced demand, industry analysts already expect that the number of service stations and refineries will decline in the 1980's. Remaining stations and refineries should be financially stronger and better able to adapt to gasoline price increases. Any reduction in highway trust fund revenues could presumably be balanced by proceeds from the gasoline tax or other taxes.

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[14] See Hans H. Landsberg, *Energy Policy Tasks for the 1980s*, RFF reprint 174 (Washington, D.C.: Resources for the Future, 1980).

*Taxes on gasoline (per gallon) in 1979 were, as examples, $1.59 in France, $0.88 in the United Kingdom, $1.14 in West Germany, and $1.58 in Italy.

[15] Demand response is difficult to quantify because there is only limited past experience with periods of gasoline price increases ("preenergy crisis" conditions appear to be of limited value for predicting "postcrisis" consumer behavior); crude oil and transportation fuel prices affect consumers in dynamic multiple ways to alter real income and demands; and it is difficult to understand demand response when vehicles have many different attributes, of which fuel efficiency is only one. (See *Motor Vehicle Demand Models: Assessment of the State of the Art and Directions for Future Research,* prepared by Charles River Associates, Inc., for the U.S. Department of Transportation, April 1980.)

*For example, OTA estimates that about half of the 0.5 MMB/D reduction in gasoline consumed by autos in 1978-80 was due to reduced driving, while about half was due to increased efficiency of vehicles in use.

Economywide Taxation— Special Provisions

Special taxation provisions are often applied at the economywide level to promote investment (e.g., by encouraging capital formation and restructuring cashflow positions). Examples of such provisions are investment tax credits, depreciation allowances, R&D tax credits, and capital gains. As with other taxes, special taxation provisions could have differential impacts on industries and distort private returns to capital. Both the auto and synfuels industries (as well as the electric utility industry), being capital-intensive, could benefit from special taxing provisions. The scope for additional special taxing provisions, however, is believed to be limited because of the many existing provisions.

Although a firm would generally have to be profitable to take advantage of special taxation provisions, tax credit sales rules have been expanded and liberalized to give unprofitable firms the chance to sell their investment tax credits and depreciation rights. The auto industry has already taken advantage of liberalized rules for selling tax credits.[16] This type of sale can help to strengthen the financial position of the auto industry, although it does not directly encourage increased fuel economy.

It is speculative to analyze how special taxing provisions would stimulate investment in synfuels. Special taxing provisions have historically been applied at the sector-specific level for domestic oil producers in the form of special depreciation allowances, and currently for expensing drilling costs and for foreign tax credits.

Research and Development

Government policies and programs could stimulate technical R&D at either the economywide or sector-specific levels to help displace oil imports. The primary rationale for Government support of R&D is that there are social benefits from R&D which surpass private gains, in large part because of high front-end learning costs. In addition, the Government tends to support research that is too risky for private funding, and which does not, for a variety of reasons, attract private investment in the short term. A major advantage of Government support for R&D is that programs can assist the economy, and specific industries, without direct intervention. However, the types of basic research that Government has traditionally supported often have benefits only in the long term, so a nearer term oil import savings implies Government involvement in shorter term R&D areas. Applied R&D also offers the opportunity for the Government to acquire equity in projects or royalties from the results of the R&D.

Economywide R&D support could be designed to stimulate opportunities for displacing oil imports generally and for both increasing automobile fuel efficiency and accelerating synfuels production. Such measures could, as examples, sponsor basic research, promote the climate for technical innovation (e.g., increasing the rewards to innovators through patent laws and/or special tax incentives), or establish mechanisms for assembling and disseminating technical information. Such nonspecific support, however, is unlikely to have much impact on resolving the specific technological uncertainties that impede both auto fuel-efficiency increases and synfuels development.

Although the Government has supported sector-specific R&D in the past, policies have seldom supported product development with direct commercial application except in agriculture and nuclear power. Research to increase automobile fuel economy and to develop synfuels, as well as other technologies for displacing oil imports, would have direct commercial application.

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[16] For example, Ford Motor Co., with losses in excess of $700 million in 1981, sold its tax credits on 1981 equipment purchases for somewhere between $100 million and $200 million to IBM (*Washington Post*, Nov. 11, 1981).

There has not yet been any substantial Government support for R&D to assist the automobile industry. Several R&D and technology demonstration programs have been Government-sponsored, and a joint industry-Government-university R&D program (the Cooperative Automotive Research Program) was attempted unsuccessfully in 1979-80.[17] Some of the basic research areas that could result in substantial long-term fuel-economy payoffs include:

1. the engine (e.g., advanced alcohol-fueled engines, nonsteady-state combustion, microprocessor controlled fuel injection, high-temperature materials);
2. vehicle structure (e.g., crashworthiness);
3. aerodynamics;
4. friction, lubrication, and wear;
5. innovative production technologies for lightweight materials; and
6. exhaust emissions.

The Government might also continue to provide some support for the advanced development of electric and/or hybrid vehicles, alternative engines, and alternative automobile fuels.

The technical uncertainties associated with synfuels development are substantial. It is OTA's judgment that, even in the presence of favorable economywide conditions, investors would not have sufficient incentive to accelerate synfuels development because of the magnitude of the technical risks associated with process technologies. For example, one of the major components of technical uncertainty is concerned with the flow and abrasive properties of solid/liquid process streams. Gaining a basic understanding of the properties of these streams so that equipment will function properly is both a theoretical and an empirical engineering challenge. At present, engineers must proceed to full-scale commercial plants without adequate analytical descriptions of how well designs will work. OTA believes there may be considerable benefit in continuing the original concept of a demonstration program to provide technical information. The results of both basic and applied research could lead to important near- and long-term advances in synfuels technology, as well as in other technologies concerned with solids handling.[18]

Trade Protection

Trade protection—tariffs and duties, quotas, local content requirements—has economywide implications but has traditionally been used to temporarily insulate specific industries and products from foreign competition. The case for import protection for the domestic auto industry is based on the claim that the industry requires only temporary protection in order to increase sales and thus to improve its revenue position, to generate capital for reinvestment, and to position itself for manufacturing fuel-efficient cars. On the other hand, it is argued that temporary trade protection would neither ameliorate the short-term competitive problems of the industry nor promote long-term restructuring for fuel economy. It is seen as inefficient and indirect adjustment assistance that can lead to higher consumer prices due to reduced competition, to higher production costs for those industries that must compete, unsubsidized, against autos for resources, and to less innovation in general. Trade protection could also lead to retaliation on the part of trading partners, and some measures are restricted by the General Agreement on Tariffs and Trade (GATT).[19]

Import quotas are generally considered less efficient than tariffs in reducing imports and stimulating domestic industries. This inefficiency arises because quotas directly distort both production and consumption (whereas tariffs change relative prices), and quotas can be bypassed with product differentiation. Duties have not generally figured in the policy debate,* but U.S. auto manufacturers have been granted temporary trade protection in the form of a 3-year Japanese automobile quota agreement. The ultimate effects of these quotas on the domestic industry are unknown, but thus far the impacts of import restraints appear to be small due to low new-car sales. However, if new-car sales recover, the prices of all small cars could increase to the extent that shortages are artificially induced by the trade restrictions.

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[17] The Justice Department also recently agreed to ease restrictions which had barred the four major manufacturers from working together on development, as well as sale and installation, of pollution control devices. See *The Washington Post,* Nov. 10, 1981.

[18] See also "Report to the American Physical Society by the Study Group on Research Planning for Coal Utilization and Synthetic Fuel Production," *Rev. Mod. Phys. 53,* 4 (pt. 2), October 1981.

[19] "General Agreement on Tariffs and Trade," 55 U.N.T.S. 194, T.I.A.S. No. 1700 (1947).

*Duties on car imports into the United States are 6 percent; this compares with 14 percent into Canada, and 11 percent into France, Italy, Germany, and the United Kingdom.

Local content provisions are another form of trade protection that has been discussed in the context of the domestic automobile industry (H.R. 5133). These measures would not displace oil imports directly but could help to protect domestic automobile manufacturing jobs. Such provisions are generally viewed as being economically inefficient, although they could serve other social/equity objectives.

Trade protection is not likely to address any of the major issues on which the future of the synfuels industry depends. Trade concerns may eventually arise if large quantities of materials and equipment are imported to construct synfuels plants or if the United States is in a position to export synfuels products or production experience.

Trade protection could be used to limit oil imports directly. Such a quota, however, could lead to domestic shortages and price increases in the absence of replacements. The Carter administration placed a quota on oil imports (and explored alternatives for allocations within the United States should demand exceed the quota), but it was set at a level which did not influence imports. Import quotas were also in effect from 1959 to 1971.[20]

Sector-Specific Demand Stimuli—Purchase Pricing Mechanisms

Demand for increased automobile fuel economy is an extremely important factor influencing the rate of increases in new-car fuel efficiency. Autos are large, long-term, and deferrable investments for consumers. Furthermore, the decision to buy a particular car depends on many attributes, of which fuel economy is only one. Imported oil will not be displaced by the manufacture of more fuel-efficient cars unless these cars are actually bought. Demand uncertainty can be reduced, and the demand for fuel-efficient cars can be stimulated, by raising the costs to consumers of buying and operating inefficient cars and/or by lowering the costs of owning relatively efficient ones. The risks to manufacturers of producing fuel-efficient cars could thus be reduced. Car ownership costs can be altered by taxing gasoline, as discussed, or by taxing/subsidizing automobiles directly.

Synfuels per se should not be directly influenced by consumer behavior except insofar as weak demand for liquid fuels limits the profitability of synfuels production. Some synfuels, however, may not fully conform to end-use fuel specifications without more extensive processing or end-use equipment modifications. The extent of this potential demand problem cannot be determined in the absence of end-use testing, but is likely to be minor except for alternative fuels such as methanol.

Purchase Taxes and Subsidies

Automobile purchase taxes or price subsidies can directly change the costs of owning cars of differing fuel efficiencies. Purchase pricing mechanisms can be linked either implicitly or explicitly to fuel-efficiency performance criteria. Current taxes are now only loosely related to CAFE standards. The extent to which additional measures would discourage the purchase of inefficient cars, or encourage the purchase of efficient cars, depends on many factors, including the level of the effective tax (or subsidy), the range of vehicles affected, the extent that auto manufacturers' pricing policies counteract the effect of the taxes (or subsidies), and the responsiveness of consumer behavior to changes in car prices.* There is also some risk that price subsidies targeting only domestic vehicles could violate the GATT provisions which prohibit most-favored-nation trading partners from taking actions that discriminate against imports from one another.

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[20] "Energy Policy," 2d ed., Congressional Quarterly, Inc., Washington, D.C., March 1981, p. 30.

*The difficulty in quantifying elasticities (i.e., the percentage change in demand for a 1-percent change in price) is discussed in "Economywide Taxation—Oil Imports and Gasoline." The International Trade Commission analysis of the Carter gas-guzzler tax proposal implied an elasticity of demand for subcompacts of −0.79 (i.e., sales of subcompacts increase less than proportionately with decreases in their prices) and an elasticity of demand for full-size cars of −1.12 (i.e., sales of full-size cars decrease more than proportionately with increases in their prices). Assuming that these figures are accurate, to reduce full-size car sales by 50 percent, for example, their prices should be raised by about 45 percent, or at least $3,500.

Low-interest loans for consumers could stimulate the purchase of all new cars, which are generally more efficient than the average car on the road. By tying the interest rates to the new car's fuel efficiency, sales of the more fuel-efficient new cars could be stimulated.

Gas-guzzler taxes, as another type of pricing mechanism, would reduce the demand for relatively fuel-inefficient cars. However, because such taxes do not discriminate among different types of users, a disproportionate share of the taxes could be paid by those who are most constrained to using large vehicles. An equity argument can be made for excepting certain classes of drivers in a tax program (e.g., taxis, hearses). Income support programs could aid in the cases of financial hardship; and tax proceeds could be used to fund these relief measures.

Both purchase subsidies and taxes may additionally and at least temporarily strain the revenue position of U.S. automakers because they are the principal suppliers of large cars, but subsidies could strengthen their long-term position due to increased car sales.

If Congress wishes to avoid discrimination against large cars (which are inherently less fuel efficient than small cars), purchase taxes or subsidies could be based on the fuel efficiency of a given model relative to other models within the same size or market class. This type of approach would lead to numerous cases where less fuel-efficient cars are taxed at lower rates or subsidized at higher rates than the more fuel-efficient ones, but it would create a demand for cars with less powerful engines and technologically improved cars (as opposed to simply smaller ones) and it would not favor imports in most cases.

Bounties

Another way to use purchase pricing mechanisms to stimulate rapid fleet turnover to higher fuel economy is by offering a gas-guzzler bounty. Bounties could be designed, as examples, as full payment for a trade-in, or as a payment upon proof of scrappage of a fuel-inefficient car. Because consumers are relatively unresponsive to changes in prices,[21] the bounty would have to be large to induce significant increases in sales of more fuel-efficient cars. For example, if a value of −0.3 is assumed for the price elasticity of demand for new cars, then for total new car sales to rise by 10 percent, net prices would have to fall by one-third. Since the average new car costs about $8,000 in 1980-81, a bounty of about $2,700 would be necessary on average to raise new-car sales by 10 percent. Since many used cars have market values under $2,700, this scheme would be profitable for the owners of used cars. However, it would be costly both to the Government and to potential buyers of used cars.

The bounty price would become the effective minimum used-car market price and all used-car prices would be proportionately increased. Because bounties distort existing relationships and operations of both the new and used car markets, bounties would be difficult to design and implement efficiently. Unless bounties were tied to high-fuel-efficiency car purchases, they might neither help manufacturers nor lead to significant fuel savings.

Registration Taxes

Car registration taxes represent another demand-side stimulus. These taxes would affect the owners of all automobiles, and they could be explicitly tied to fuel efficiency or some surrogate measure* to encourage replacement of fuel-inefficient cars. However, they would make auto ownership more expensive regardless of the amount and nature of the travel, and they would work towards reducing demand for autos in the long run. By effectively lowering consumer income, registration taxes would also disproportionately affect low-income groups.* In addition, a registration policy implies State action, and consistent, concerted implementation may be difficult to achieve.

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[21] "Motor Vehicle Demand Models: Assessment of the State of the Art and Directions for Future Research," prepared by Charles Rivers Associates, Inc., for U.S. Department of Transportation, April 1980.

*One possible measure would be ton miles/gallon (e.g., how much a vehicle weighs per rate of fuel use). Several foreign countries already have registration taxes that depend on automobile weight and/or engine size.

An important possible side effect of all demand-side stimuli which have the effect of reducing large-car demand is that only those domestic manufacturers with a clear competitive advantage in producing large cars will continue to serve this shrinking market. This reorientation of domestic production would be consistent with long-term international trends towards corporate consolidation and a standardized "world car."

Methanol

Promoting the use of methanol as an automobile fuel is likely to require coordination of supply and demand stimuli. A limited supply of methanol, however, is currently available from the chemical industry.**

Automotive uses of fuel methanol are principally in a blend (with cosolvents) in gasoline or in engines designed or converted to use straight (neat) methanol. Because many automobiles now on the road cannot accept methanol-gasoline blends with more than 1 to 3 percent methanol, the blend market for methanol is currently quite limited (less than 50,000 B/DOE); but the potential market could be expanded if incentives were provided to make new cars compatible with higher percentage blends. This would also add flexibility with respect to matching supply and demand, which would help to avoid methanol fuel shortages and gluts. The use of blends could be encouraged through direct subsidies and through approval of methanol by EPA as a blending agent in gasoline.

Demand for fuel methanol can also be stimulated with incentives to convert captive fleets*** (current fuel consumption by larger fleets is about 0.6 MMB/DOE[22]) to methanol. Captive fleets are currently more attractive for neat methanol use than privately owned cars because fleets often have their own fuel storage and pumping facilities, which can be converted to methanol at the same time as the fleet conversion.

Introduction of vehicles for general use which are fueled with neat methanol probably will require coordinated planning to ensure that neat methanol is available at service station pumps at about the same time or before the vehicles appear for sale. However, if this fuel supply problem can be solved (see supply stimuli below) and methanol is available at prices (per Btu) comparable to gasoline, it is likely that some auto manufacturers will supply alcohol-fueled vehicles without Government incentives.

Sector-Specific Supply Stimuli—Subsidies and Guarantees

Supply-oriented stimuli—in the form of direct subsidies, grants, and loan, price, and purchase guarantees—are methods for quickly providing visible and directed sector-specific support to industries and firms.[23] These stimuli, by shifting a portion of the costs and risks to the Government, can provide a temporary inducement to firms to accelerate investments (i.e., to the auto industry to increase fuel economy and to the synfuels industry to accelerate production). Supply-oriented stimuli can also be structured so as to minimize or alleviate costly side effects associated with the investment or stimulus. The rationale is that market-driven business practices would not provide, at the time required, nationally desirable output levels.

Sector-specific, supply-oriented policy measures share the disadvantages described earlier that are associated generally with any sector-specific policy approach. In addition, they could put direct pressure on the Federal budget. Detailed analysis is required to ensure that policies and programs do not perpetuate inefficient operations, that production changes and other efficient innovations are not being discouraged, and that targeted manufacturers are not benefiting inequitably. A major implementation problem is in linking of payment with performance: to ensure that supply-oriented mechanisms promote oil displacement, they would need to be contingent on savings or production performance. Ideally, a detailed study of the many factors that determine fuel use could illuminate how much stimulation would be required to reduce oil imports and how such measures would affect the Nation's energy bill. In practice, however, any such study is likely to have numerous shortcomings and inaccuracies.

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*Other fees that could discourage fuel use by all drivers include commuter taxes, car-pooling incentives, and parking fees.

**Total U.S. methanol production, which comes from natural gas and residual fuel oil, corresponds to about one 50,000 B/DOE synfuels plant or about 1.5 billion gal of methanol per year.

***A captive fleet is a fleet of cars or trucks owned and operated by a single business or Government entity and often used primarily in a localized area with central refueling facilities also owned and operated by the fleet owner.

[22] The Department of Energy ("Assessment of Methane-Related Fuels for Automotive Fleet Vehicles," DOE/CE/50179-1, vol. 2, pp. 5-23, February 1982) has estimated that automobile fleets of 10 or more, truck fleets of 6 or more, and bus fleets consume about 0.6 MMB/D of gasoline and about 0.4 MMB/D of diesel. Replacing all of the gasoline would require about 20 billion gal of methanol per year.

[23] See *An Assessment of Oil Shale Technologies,* OTA-M-118 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June, 1980).

Loan Guarantees and Grants

The principal sector-specific supply-oriented policy mechanisms are loan guarantees, price and purchase commitments, and direct grants. Of these, grants are the most advantageous for investors, since they are a form of direct assistance. Grants for improving auto fuel efficiency and producing synfuels may be unpopular because both alternatives are sponsored by the private sector and have profit-generating potential. Objections to direct grants could be offset somewhat if the Government purchased equity in the companies with the money.

Loan guarantees are also advantageous to investors because they allow investors to reduce their financial exposure in case of default. Unlike grants which require that the Government appropriate funds immediately, loan guarantees require Government payment only in the event of a company's default. Loan guarantees have been applied to both the auto and synfuels industries. In the case of autos, loan guarantees were administered by the Government to the Chrysler Corp. when it judged that the costs of **not** intervening would be unacceptable from a national viewpoint. These loan guarantees represent a break with historic policy. No direct aid had previously been given because the industry as a whole was profitable and there was a reluctance both on the part of the Government to subsidize the private sector (except under unusual circumstances) and on the part of the private sector to accept Government support and related conditions.

Three policy complications also would arise when considering subsidizing domestic auto manufacturers:

1. determining the eligibility of foreign firms that establish production subsidiaries in the U.S. (e.g., Volkswagen of America, Honda);
2. compliance with GATT provisions; and
3. the treatment of auto suppliers.*

Loan guarantees are administered by SFC under ESA for the synfuels industry. These guarantees have been justified on the basis that the costs and technical risks of synfuels production are so great that, in the absence of loan guarantees and other supply-oriented stimulation, private investment would be slow in coming. With the large (75 percent) guaranteed loans that are possible under ESA, investments in synfuels appear to be attractive.** Industry has generally favored Government support in the form of loan guarantees to stimulate investment, and OTA believes that this is an effective way of making synfuels investments financially attractive.[24] Because of general inflation and steady increases in the estimated costs of synfuels projects, however, the funds currently available to SFC and the limitation of about $3 billion in aid per project may not be adequate to support the number of projects originally envisioned or allow a full 75-percent loan guarantee for the larger projects.

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*Although many suppliers will have to invest to accommodate automotive change, it may be most efficient to subsidize only manufacturers, who would in turn, fund suppliers as appropriate, for two reasons: first, the amount of U.S. supplier investment (and to a lesser degree U.S. manufacturer investment) depends on the amount of outsourcing and the degree to which foreign supplies are used; and second, it is easier to deal with the handful of manufacturers than the thousands of suppliers they may use.

**The 61 proposals received by SFC in its first general solicitation are a preliminary confirmation of this. These proposals reflect the variety of approaches considered viable by private industry: 14 oil shale projects, eight tar sands (including heavy oil) projects, one coal-oil mixture project, one solid-fuel additive from coal project, and one hydrogen-from-water project. Of course, general economic conditions, as well as the price of imported oil, will also have a major impact on the decisions of private investors. These conditions will, in turn, heavily influence the terms that SFC is able to negotiate as it seeks to employ the funds available to it.

[24] Ibid.

Purchase and Price Guarantees

Purchase and price guarantees protect investors by ensuring that products can be sold at a price equal to or greater than the minimum guaranteed, regardless of market conditions. But unless the price is set at extremely high levels, these incentives do not ensure against losses that occur if initial estimates are wrong with respect to cost, price, production volume, or product quality. These guarantees are most appropriate when market demand and price are the major uncertainties (and are expected to be "too low"), where commodities are homogeneous, and when commodities have a value to the Government in use or resale. They could, however, distort relationships among producers and consumers; they can be administratively complex, and they do not reduce investors' financial exposure in the case of poor performance.

Purchase and price guarantees have generally not been considered viable for the auto industry because of the differentiation of its products and the complexity of manufacturer-dealer-consumer relationships.

Although purchase and price guarantees do not address the central technical uncertainties of synfuels production, they may nevertheless be useful in conjunction with other incentives. Provisions for price guarantees and purchase commitments are included in the 1980 synfuels legislation.

Subsidies and guarantees can lead to large annual investments by the Government. For example, given that 6 to 8 million cars are produced domestically each year, subsidies of several hundred dollars per car for fuel-economy improvements (which corresponds to the investments needed to make the necessary changes) could require annual expenditures of several billion dollars.

To illustrate the magnitude of subsidy that could be necessary through a price guarantee to accelerate synfuels production, assume that crude oil costs $40/bbl, that synfuel from a newly opened 50,000 B/DOE plant requires a $10 subsidy for each barrel of oil replaced, and that synfuels production costs follow general inflation. If the real price of oil were to escalate by 2 percent per year, the synfuel would have to be subsidized for 11 years at a total cost of about $1 billion. If the real price of oil escalates at 4 percent per year, the period of subsidization and the total cost would be half as large. Similarly, a 1-percent real inflation rate for oil would double the duration and magnitude of the subsidy. Thus, price guarantee subsidies can reach levels that are a significant fraction of the investment initially needed to build the plant.

The Government could, however, require repayment of a subsidy if the manufacture of fuel-efficient cars or the production of synfuels became profitable without subsidies.

Methanol

The supply incentives mentioned above and those described under "demand stimuli" are probably adequate to encourage production of methanol from coal for use by the chemical market and some captive fleets of automobiles, and, possibly, as blends in gasoline. However, additional supply incentives may be necessary to encourage the use of methanol in automobiles which are not part of a captive fleet.

Once significant quantities (probably more than 0.1 to 0.2 MMB/DOE) of methanol are being used in captive fleets and, possibly, in gasoline blends, it may be possible to offer methanol for sale to the public in enough places to make ownership of a methanol-fueled vehicle practical for individuals. Incentives can be offered to owners of methanol-fueled captive fleets, who have their own methanol storage and pumping facilities, to sell methanol to the public. Incentives can also be given to service station owners who sell methanol blends to install methanol storage tanks and blend the methanol with gasoline at the pump. They could then sell straight methanol, as well.

Many owners of captive fleets probably cannot be easily induced to offer methanol for sale, because it would not be related to their other business activities and would be tantamount to entering the service station business. Similarly, very large economic incentives may initially be necessary to induce service station owners to install methanol facilities, because the investment would not lead to a near-term increase in sales.

On the other hand, it could be mandated that any supplies of methanol used for Government-owned captive fleets be made available for public sale. And some captive fleet and service station owners would be willing to offer methanol to gain an early market share or for the financial incentives offered by the Government. If these monetary and nonmonetary incentives were adequate, methanol could compete directly with gasoline and diesel fuel as an automobile fuel.

Regulations on Output

One of the most direct policy mechanisms for promoting alternatives that can displace oil imports is regulation. Regulations are a common, if controversial, form of Government intervention in the economy. Although their effects can be felt economywide, regulations are typically directed at specific industries or products. In general, they would target the supply aspects of oil import alternatives. Measures could also be designed to target consumers (e.g., the 55-mph speed limit, end-use fuel restrictions in the stationary sector), but the Government has traditionally been reluctant to mandate changes in consumer behavior and habits.

Regulations can be designed for two major purposes. First, they can serve to protect the public from the side effects caused by the conduct of industrial activities. These effects include impacts on the environment, health, and safety which are discussed in the next section. Regulations can also be used to determine outputs directly—the level of consumption or production of fuels—if the market is unable to ensure desirable levels.

The auto industry has been regulated in the United States in the areas of emissions, safety, and more recently fuel economy. The major Government program mandating fuel-efficiency increases is the CAFE standards. Whether or not to increase these standards beyond levels set by current legislation for 1985 and beyond may be a major upcoming decision before Congress.

Effectiveness of the CAFE standards in spurring fuel economy improvements is controversial. An important feature of these standards is that they are effective only if they force manufacturers to do more than consumers demand. This increases the investment risks since, although regulations can affect the supply of fuel-efficient cars, they do not directly influence purchases. Through the 1970's consumers failed to demonstrate a consistent demand for fuel economy,[*] and the CAFE standards probably increased fuel efficiency above what the market would have achieved. And recent data (fall 1981) show that, in fact, the proportion of relatively large cars sold has once again increased compared with the number of smaller cars sold.

The arguments for extending CAFE standards beyond 1985 are inconclusive. To the extent that CAFE standards are met through sales of smaller cars, as opposed to purely technological changes, U.S. manufacturers must increasingly compete with imports for the small-car market. Increasingly stringent fuel economy standards could, therefore, result in higher import levels if domestic manufacturers are unable to increase their competitiveness in this market, despite the product changes they have made. Post-1985 standards are also likely to require additional capital for more rounds of redesigning and retooling. But post-1985 standards could result in important fuel savings to the Nation, especially if the demand for fuel-efficient cars remains sluggish. Additional demand stimuli may also be necessary, depending on national and international conditions, to ensure that fuel-efficient cars are bought.

In considering the effects of CAFE standards it is important to recognize that CAFE standards do not distinguish among average efficiency increases that result from: 1) technological improvements, 2) consumers' purchasing the more fuel-efficient cars in each size class, and 3) consumers purchasing smaller cars. Depending on market demand, success of technical developments and auto manufacturers' financial positions and capital stock, CAFE standards could be met through various mixes of the three (see table 8). Consequently, **without special provisions** it probably is impossible to establish conventional CAFE standards which simultaneously: 1) are effective (i.e., increase new-car fuel efficiency above what market forces would dictate), and 2) do not promote the sales of small imported cars. Separate fuel-efficiency standards for each automobile size or market class could significantly reduce the indirect promotion of small-car sales; however, this would greatly reduce automobile companies' flexibility in responding to the regulations.

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[*] The drop in demand for fuel efficiency and the resurgence in large-car demand in the mid to late 1970's led manufacturers to petition (unsuccessfully) NHTSA to lower CAFE standards for the early 1980's because sluggish sales of fuel-efficient cars made necessary investments appear especially costly and risky. Market trends in the 1970's also led manufacturers to concentrate initially on improving fuel economy for relatively large cars rather than on developing new small-car designs. Manufacturers attributed their expectation to exceed voluntarily the 1985 CAFE standard of 27.5 mpg to renewed, strong demand for fuel economy arising from the 1979 oil crisis and increases in gasoline prices. This increase in demand and current industry efforts to raise fuel economy recently led NHTSA, which administers the CAFE program, to terminate rulemaking with respect to post-1985 average fuel-economy improvements (*Fed. Reg.* 22243, Apr. 16, 1981). A petition from the Center for Auto Safety that requested NHTSA to continue rulemaking was also subsequently denied (*Fed. Reg.* 48383, Oct. 1, 1981).

The NSPP sets targets for synfuels production but the mandating of synfuels output has not been of central congressional interest. The major difficulty associated with developing synfuels stems from technical uncertainties which, in turn, affect the likely cost at which synfuels initially will be produced. In addition, contributions to oil import savings from synfuels would not be made incrementally (as with increasing automobile fuel efficiency) but rather depend on the proper functioning of large-scale facilities. As experience and knowledge is gained, it may become possible to establish realistically achievable production levels if the Government desires an assured level of synfuels supply.

Table 8.—Potential Average New-Car Fuel Efficiency in 1995

Car size class	Fuel efficiency of average model (mpg)[a]
Large	30-45
Medium	45-60
Small	60-75

Size mix of cars sold	Average new-car fuel efficiency (mpg)[a]
1981 size mix[b]	40-50
Moderate shift to small cars[c]	45-60
Large shift to small cars[d]	50-65

[a] All mpg figures rounded to nearest 5 mpg. Mpg refers to the composite consisting of 55 percent EPA city cycle and 45 percent EPA highway cycle,

[b] 1981 sales: 47 percent large cars, 48 percent medium-sized cars, and 5 percent small cars.

[c] 1995 sales: 20 percent large cars, 55 percent medium, 25 percent small.

[d] 1995 sales: 5 percent large cars, 45 percent medium, 50 percent small.

SOURCE: Office of Technology Assessment.

One possible form of regulation would be to stipulate that a certain percentage of the output from domestic oil producers be synfuels. However, this provision would be unworkable for small oil producers, so it would have to be targeted at the larger oil companies. Similar problems arise with regulations aimed at refiners or retailers. Furthermore, because refining and retailing are considerably less profitable than gas and oil production, regulations aimed at the former might induce some of the companies that are vertically integrated to abandon refining rather than to incur the added costs and risks. For these reasons, it would probably be very difficult to administer mandates on synfuel content.

Other Effects

Environment, Health, and Safety

Both increased automobile fuel efficiency and synthetic fuels production have the potential for creating large-scale environmental, health, and safety hazards. A principal rationale for policy intervention is the general past failure of private markets to internalize these other effects in investment decisions and operating practices. Policies to protect the public have tended to take the form of regulations that govern known or anticipated impacts through performance standards or control specifications.

Apart from fuel efficiency, the auto industry is regulated in the areas of emissions and safety. Emissions standards require that each vehicle—and automobile safety standards require that each of certain vehicle parts—meet minimum performance standards. (By contrast, fuel-economy standards are for fleet averages.) There are proposals before Congress to delay, modify, or eliminate over 30 automotive-related environmental and safety regulations.[25]

A potential threat to the public from size and weight reduction of vehicles used to increase fuel efficiency is decreased automotive safety. The basic policy issue is whether the Government should act to help prevent future highway fatalities if consumer demand for safety does not result in adequate safeguards.* Regulatory policy could, as examples, reconsider the passive restraint program (rulemaking for that program was terminated by NHTSA although a recent U.S. Court of Appeals ruling has reinstated the program, at least for the moment), mandate the use of safety belts, strengthen crashworthiness design standards, or maintain or tighten speed limits. Other types of programs could provide for stricter driver licensing standards and improved road maintenance and traffic control, support R&D, and provide for driver safety education. Another potential adverse effect is the air quality impact of a large increase in diesel-powered autos. Policy alternatives include more stringent particulate and NO_x emission regulations for diesel engines and Government assistance in diesel health effects research and emissions control development.

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[25] See Gwenell Bass, "The U S. Auto Industry: The Situation in the Eighties," CRS issue brief No. IB81054, Sept. 30, 1981.

Potential environmental and worker-related problems associated with synthetic fuels development (e.g., contamination of drinking water, release of cancer-causing agents and other hazardous pollutants, highly visible plant upsets, obnoxious odors, and localized water availability conflicts) are substantial and have considerable potential for arousing strong public opposition. There are also elements of the present synfuels development strategy that appear to increase the potential for adverse impacts. These elements include the proposed siting of some synfuels demonstration plants close to heavily populated areas, research budget cuts at EPA and the proposed dismantling of DOE, the current policy to shift environmental management responsibilities to State and local agencies without a concomitant shifting of resources, and an industry environmental control program that appears reluctant to commit resources to currently unregulated pollutants and that may be overconfident about the performance of integrated control systems.**

Finally, the multiplicity of pollutants associated with synfuels production and the difficulty of detecting and evaluating some of the potential impacts (e.g., long-term cancer impacts from low-level exposures), coupled with the above factors, leads to a strong concern about the adequacy of future regulation of a synfuels industry.

Government actions targeted at the potential risks of synthetic fuels development may be an important factor in assuring that the risks are properly measured and in causing the private sector to account for these risks. A problem the Government faces, however, is that premature adoption of rigid standards could ultimately act to stifle innovation or force suboptimal environmental decisions. Also, the capital-intensive nature of the industry leaves it vulnerable to delays caused by shifts in environmental requirements or standards that ultimately prove unattainable.

The existence of these problems places a premium on an intensive research program and a round of demonstration plants, that include full environmental control systems, to avoid surprises and provide timely information for intelligent regulation. Also, the impact of an environmental surprise might be minimized by choosing isolated sites and requiring particularly strict controls for the first round of plants, thus minimizing the actual impact suffered from excessive discharges or other problems.

The vulnerability of synfuels plants to scheduling delays has also generated pressures on Congress and State legislatures to streamline environmental permitting for energy facilities. Although it is too early to assess recent streamlining efforts at both the Federal and State levels, considerable improvement appears possible **without** a full-scale Energy Mobilization Board.[26] In most cases, regulatory delays are important only to the extent they delay construction starts or require changes in plant design; otherwise, all necessary permits are likely to be obtained before significant construction investment has been made. Delays after construction has started could, however, be costly. A 3-year delay, for example, could increase synfuels product costs by 20 percent or more. In addition, the risk that retrofitting may be required will remain until synfuel processes have been proven and both emissions and products extensively tested. Formulating regulatory policy entails an assessment of the full range of regulatory costs to industry versus the possible costs arising in the absence of policy. At present these complex tradeoffs are often determined in a lengthy, case-by-case process based on judicial interpretations.

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*Manufacturers may not pursue safety for fear that the added cost will dampen market demand. In most cases safety has not been a strong selling point in automobiles in the past.

**In apparent response to their confidence that adequate environmental control of synfuels plants will involve only "fine tuning" of existing control technologies, developers have passed up some opportunities to test out control systems on demonstration plants. For example, Exxon feeds the wastes from its Baytown, Tex., EDS plant into a neighboring refinery rather than developing and testing specific controls for the plant. In OTA's opinion this increases the risk of unforeseen problems at the first large-scale plants. Such problems appear quite possible given the differences between the conditions under which proposed control systems have been used previously (in chemical plants, refineries, etc.) and the expected conditions in synfuels plants.

[26] Congressional Research Service, "Synfuels From Coal and the National Synfuels Production Program: Technical, Environmental, and Economic Aspects."

Policy alternatives to regulation include effluent charges and pollution vouchers. Although such mechanisms have a strong theoretical basis, there is a general lack of practical experience in using them. Also, the toxic pollutants of most concern in synfuels production cannot safely be traded off among sources the way pollutants such as SO_2 and NO_x can be.

There are two additional levels for policy involvement. First, Congress could decide to increase the environmental capabilities of responsible regulatory agencies. One specific option is to target resources for specific State and local environmental agencies, as was done under the Clean Air Act in the early 1970's. As a part of this option, Congress may also wish to investigate the effects of the programmatic changes and budget reductions for synfuels environmental research and control system development at EPA and DOE.

Secondly, environmental concerns could be integrated directly into financial support decisions —i.e., of SFC. Although some would claim that this latter option is redundant given current environmental legislation, there are nevertheless many concerns (e.g., siting) which are not well-addressed by existing laws. In addition, the protection of SFC investments would be well-served by an ability to influence environmental planning. SFC has not yet moved aggressively to build a technical capability for the environmental assessment of projects it will support.

The availability of water resources may pose special problems for policy because of the present controversies surrounding the allocation and use of increasingly scarce supplies.[27] How conflicts are resolved in areas where users presently or could potentially compete for water will have important implications for the distribution of costs and benefits to all water users, especially since the costs of procuring water are likely to be small (in comparison with other costs) for the synfuels industry. Present water policies and planning mechanisms are fragmented and generally inadequate to assess water availability and plan for future water needs on a consistent, comprehensive, and continuous basis. Because of the magnitude, diversity, and nationwide distribution of water resource problems and because the outcome of water-resource allocation conflicts will have local, State, regional, and National impacts, the Federal Government has an important role to play in improving water resource management practices in cooperation with the States. Major policy issues include the resolution of uncertainties surrounding water rights and future water needs and the definition of responsibilities, objectives, and priorities for water planning and allocation. Legislation pending before Congress (e.g., S.1095 and H.R. 3432, which both call for the dismantling of the U.S. Water Resources Council) seeks to redefine the respective responsibilities of Federal and State Governments and to clarify the role of regional and local interests in managing water resources.

Social Adjustment Assistance

Increasing automobile fuel efficiency and developing a synfuels industry will result in social costs and benefits which are side effects, i.e., effects that are external to the transactions made between consumers and producers. The movement of capital and labor as a result of industrial change (i.e., restructuring, contraction, or growth) will have implications not only for the character of the labor market but also, consequently, for lifestyles and standards of living.

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[27] For further discussion of these issues see *An Assessment of Oil Shale Technologies*, OTA-M-118 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1980); and *A Technology Assessment of Coal Slurry Pipelines*, OTA-E-60 (Washington, D.C., U.S. Congress, Office of Technology Assessment, March 1978).

In the auto industry, the major social effects are related to job losses resulting from structural adjustment. In the synfuels industry, the major social externalities are related to new employment and result from large, rapid and fluctuating population growth in some areas where the industry may locate. Government policy may be important both for easing those social adjustments that the market does not address and for ensuring that associated costs do not fall disproportionately on particular groups. Social-adjustment assistance in this country has generally been limited in the past to sectors affected by international trade and to several programs focusing on regional adjustment.

Labor market dislocations are of primary importance to the Nation because of the penetration, numbers, and dispersion of auto-related jobs throughout the economy as well as the geographic concentration of auto production jobs. Restructuring of the industry for improved international competitiveness, productivity, and fuel efficiency is resulting in what is likely to be a long-term decline in auto-related employment.

The problem of unemployment in the auto industry could be addressed by policy measures that seek to ease the adjustment of firms, workers, and communities to changing economic conditions. Policy options include, as examples: relocation assistance, support of retraining programs and training institutions, local content provisions, manpower training vouchers for targeted individuals, plant-closing restrictions, tax incentives to other industries (or regions) to attract displaced workers, and community aid programs (e.g., to diversify local economies).

Some assistance has been available under the Trade Act of 1974 provisions and through Housing and Urban Development, the Economic Development Administration, and other Government agency programs. These programs have generally been limited in scope and funding and have generally required evidence of economic distress (i.e., they are not preemptive). They are also candidates for curtailment under proposed Federal budget cuts. Note that because employment displacement depends in part on labor costs, automobile-related employment levels will also vary with the degree to which autoworkers accept changes in compensation and work rules, behavior which is not generally subject to direct Federal policy initiatives.

Major social side effects arise from synfuels development because the communities which absorb the large, rapid population increases (a portion of which is only temporary) are vulnerable to institutional and social disruptions. These externalities could constrain synfuels development by generating public opposition to synfuels and by adversely affecting worker productivity. The principal policy issues relate to who will bear the costs of managing and mitigating these disruptions and how up-front capital can be made available to finance necessary public facilities and services. Those who view social impacts as the price of regional development emphasize the responsibilities of State and local governments working with private developers. Those who associate local impacts primarily with the pursuit of national energy objectives call for a continued and expanded Federal role.

There are also many questions of equity that arise in allocating resources among different areas, because of the large variations in the magnitude and character of adverse impacts and the resources available to cope with these impacts. An acceptable assistance program must deal with the problem that some of the shortages of impact-mitigation resources are caused by limitations on planning and borrowing powers imposed by local and State governments themselves.

Current policies to deal with the social impacts of energy development are unable to address consistently and comprehensively the cumulative impacts arising from the large-scale, rapid-growth situations that characterize synfuels development. Government policies could be directed at either energy development generally or synfuels production specifically, and could provide, as examples: financial aid, technical assistance, growth management planning assistance, regulation (e.g., with respect to siting, phasing, pacing, monitoring), lending and borrowing assistance, or taxing provisions. The various forms of technical and financial assistance for growth management are examined in detail in previous OTA studies.[28] [29] [30] [31] All relevant Federal programs have been targeted for substantial budget reductions, or elimination, in fiscal year 1982 under proposals submitted to Congress by the present administration.[32]

The development of a synfuels plant will lead to the creation of new jobs in construction and engineering. Technically qualified personnel should be available for most of these jobs. However, a shortage of experienced chemical process engineers and project managers could arise, causing costly mistakes and production delays. The overall number of chemical process engineers, for example, would have to increase by about one-third by the mid to late 1980's to accommodate an optimistic level of synfuels plant construction.

The Federal Government could encourage the education of engineers by providing financial support for facilities, equipment, retraining programs, scholarships, and the hiring and retraining of faculty. Training in skills needed for complex project management could similarly be stimulated. The auto industry would also benefit from programs to train engineers if the industry pursued extensive development efforts domestically.

CONCLUSIONS

Both increasing automobile fuel efficiency and synfuels production have economic and noneconomic risks and external costs. The decision to pursue either, or both, alternatives—as well as to pursue the third major technical alternative of fuel switching and conservation in stationary uses of petroleum—depends on the desired rate and level of oil import displacement and what the Nation is prepared to spend to achieve its oil-displacement goals.

The availability and cost of capital are especially important for the automobile and synfuels industries, since they are both capital-intensive. General economic conditions affect consumer confidence and purchasing power. Among the policies mentioned in this chapter are general tax policies and special taxing provisions which would encourage capital formation and stimulate industrial innovation economywide.

The rate at which automobile fuel efficiency can be increased and a synfuels industry developed are also affected by factors that are specific to each alternative. Contributions to oil-import displacement from increased automobile fuel efficiency depend critically on consumer demand for fuel-efficient cars. Government actions to stimulate demand are a direct way to help ensure that fuel-efficient cars are bought and, in turn, that they will be produced. Demand-oriented measures that appear promising and that deserve further analysis include registration, purchase, and fuel taxes and purchase subsidies. Supply incentives, depending on their nature, could help manufacturers pay for the investments necessary to increase fuel efficiency, especially if there is an absence of strong demand for either cars in general or fuel-efficient cars in particular. In the case of weak demand for efficiency, increasing CAFE standards beyond the 1985 level may help to ensure continued oil import displacement. However, the increased cost of the efficiency increases could reduce new-car sales and thereby reduce the potential savings. In general, a combination of demand and supply incentives would be the most effective means of promoting more efficient fuel use in automobiles. This would contrast with past policy, which has been aimed largely at producers.

The success of synfuels development in displacing oil imports hinges on the resolution of major technical uncertainties associated with as yet unproven processes. Private investments are likely to be accelerated once processes are demonstrated in commercial-scale units—provided the processes are economically competitive sources of fuels. The high costs and other risks associated with demonstration projects are likely to necessitate Government support if synfuels production is to become a significant fuel source by the end of the century.

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[28] *An Assessment of Oil Shale Technologies,* op. cit.

[29] *The Direct Use of Coal,* OTA-E-86 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

[30] *Management of Fuel and Nonfuel Minerals in Federal Land,* OTA-M-88 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

[31] *An Assessment of Development and Production Potential of Federal Coal Leases,* OTA-M-150 (Washington, D.C., U.S. Congress, Office of Technology Assessment, December 1981).

[32] Congressional Research Service, "Energy Impact Assistance Legislation," issue brief No. IB79022, Sept. 9, 1981.

Other policy considerations for displacing oil imports are applicable generally to planning in a world of uncertainty. First, flexible and nonspecific policy interventions provide both public and corporate decisionmakers with the maximum opportunities to adjust internally to changing economic and technical circumstances. Secondly, periodic reviews and adjustments can help prevent prematurely locking the Nation into technical choices that discourage a continuing search for better methods, although too much flexibility can lead to ad hoc programs.

A long-term, stable policy commitment to oil import displacement, and to alternatives for displacing imports, is essential in order to send clear signals about Government intentions and promote mutual confidence in any public-private relationship. In the past, the Government has sometimes sent conflicting signals. For example, concurrent Government programs were in place, on the one hand, to encourage automobile fuel economy with CAFE standards and, on the other hand, to discourage fuel conservation with price controls on oil which helped to keep the price of gasoline low.*

Increased automobile fuel economy and synfuels production contribute in different ways to the Nation's energy security. The advantages of automobile fuel efficiency include the following: 1) through conservation, it directly eliminates the need for oil imports in the Nation's highest petroleum-consuming sector; 2) after large numbers of fuel-efficient vehicles have been sold, the fuel savings does not depend on the operation of a few large plants, and there will continue to be fuel savings even if particular vehicles perform below standards; 3) it does not result in a net reduction of natural energy resources and thus preserves options for future generations; and 4) although there are long leadtimes for commercializing new products in the auto industry, savings are already occurring as technologies are diffusing into the consumer market. However, if market and/or Government pressures for increased automobile fuel efficiency damage the U.S. auto industry, there will be repercussions throughout the economy.

The principal national security advantage of synfuels production is that it may provide long-term strategic insurance against sustained shortfalls. Rapid and successful deployment could conceivably serve to reduce the rate at which oil import prices increase and thus help to reduce inflation. The vulnerability of the synfuels alternative is related to the complexity of technical controls, the high risks and costs of failure, potentially hazardous environmental side effects, institutional barriers to deployment, and, in some cases, the geographic concentration of facilities.

Because increasing auto fuel efficiency and synfuels development are both capital-intensive, each will incur major economic penalties if facilities function below capacity. However, because the "normal" rate of capital turnover is likely to be lower in the synfuels than the auto industry, synfuels production will be more limited in adapting to changing demands.

Developing a long-term, coordinated, and comprehensive energy policy will be an incremental process. A prime objective is to choose a least cost mix of options for reducing oil imports. Because investment costs (per barrel per day of oil saved or replaced) for the various options considered in this report for the 1990's are highly uncertain, yet appear to be comparable in magnitude, the judgment of relative costs will depend largely on value assessments of the various externalties of pursuing each option.

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*U.S. policies in the 1970's also implicitly encouraged oil use for stationary purposes (e.g., Federal curtailment policy for natural gas).

APPENDIX 3A.—POLICY OPTIONS TO REDUCE STATIONARY OIL USE

Conservation

1. Tax credits for investments in conservation:
   - Current 15-percent credit for investments by homeowners—single-family and 4-unit or less multifamily.
   - 10-percent tax credit for energy efficiency or renewable resource investments by industry.
2. Residential Conservation Service:
   - Utility audit service for homeowners.
   - Proposed extension to include apartment and commercial buildings.
3. Subsidized loans to homeowners to finance conservation investments:
   - Currently the purpose of the Solar and Conservation Bank.
   - Private savings and loan institutions also offer below-market loans for conservation in some cases.
4. Targeted tax credits (20 percent) for investments in energy efficiency by industry:
   - Currently proposed in legislation now before Congress.
   - Tax credit in addition to current credits.
5. State public utility commission actions to encourage conservation efforts by utilities:
   - Allowance of conservation investments in the rate base of utilities (proposal).
   - Permission to sell saved energy to private investors (proposals).
   - Allowing utilities to set up separate companies to provide conservation services—now occurs in some cases.
6. Legislating standards and/or information:
   - Appliance efficiency standards—labeling of appliances.
   - Building standards—currently prescriptive standards through the minimum property standards of the Department of Housing and Urban Development.
   - Building energy performance standards are legislated but currently not enforced.
   - Efficiency standards for industrial electric motors were proposed but never enacted.

Fuel Conversion

1. Prohibition on oil use by utility boilers and large industrial boilers:
   - Principal focus of the Fuel Use Act.
   - Goal to eliminate use of oil by 1990.
2. Financial assistance for utilities to convert from oil to coal:
   - State commissions have allowed New England Electric Co. to secure a "loan" from their customers to pay for an oil-to-coal conversion.
   - Federal legislation proposed to provide loan guarantees for these conversions was never passed and is not likely to be pursued now.
3. Legislation to remove regulatory restrictions on use of natural gas by industry:
   - Currently part of several proposals to encourage conversion to natural gas.
   - Current regulations (Federal and State) either prohibit or discourage natural-gas use for many applications that now use fuel oil.
4. Environmental regulations affecting coal use in industry:
   - Lowering of emission standards for applications below a certain size.
   - Financial assistance to help install control technologies.

General

1. R&D to increase efficiency of end-use technologies:
   - Promotes general conservation.
   - Can also be directed at developing efficient electric energy using technologies to make the economics of switching to electricity attractive.
2. Tax on oil—either on imports or on specific products such as fuel oil for boilers or space heating:
3. Economic incentives for development of unconventional natural gas:
   - Currently unconventional natural gas is completely deregulated.
   - Tax credits to encourage development of unconventional gas (this is currently not available).

APPENDIX 3B.—ADDITIONAL CRS REFERENCES

The Congressional Research Service has recently published many reports on various aspects of energy policy to which the reader is referred. These reports include the following:

1. Rothberg, Paul, "Synthetic Fuels Corporation and National Synfuels Policy," CRS issue brief No. IB81139, Oct. 13, 1981.
2. Chahill, Kenneth, "Low-Income Energy Assistance Reauthorization: Proposals and Issues," CRS mini brief No. MB81227, Aug. 26, 1981.
3. Abbasi, Susan R., "Energy Policy: New Directions Indicated by the Reagan Administration's Budget Proposals," CRS mini brief No. MB81222, June 29, 1981.
4. Parker, Larry, Bamberger, Robert L., and Behrens, Carl, "Energy and the 97th Congress: Overview," CRS issue brief No. IB81112, Sept. 15, 1981.
5. Rothberg, Paul, "Synthetic Fuels Corporation, Policy and Technology," CRS mini-brief No. MB79245, July 13, 1979, updated Apr. 20, 1981.

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Chapter 4

Issues and Findings

INTRODUCTION

This chapter is a summary and comparison of major results from the analyses discussed later in the report. It also contains additional analyses where needed to put the results in perspective.

It begins with a discussion of the true cost of imported oil. Increased automobile fuel efficiency, synfuels, and conservation and fuel switching in stationary petroleum uses are then compared according to the speed with which they can act to reduce oil imports and their respective investment costs. Increased auto fuel efficiency and synfuels are compared according to their environmental, social, and economic impacts. Estimated consumer costs for increased automobile fuel efficiency and synfuels are also given in separate boxes, but the uncertainties are too large for any meaningful comparison. In addition, there is a box discussing the uncertainties in total consumer costs for each of the oil displacement options.

Following the comparisons, several issues related specifically to increased automobile fuel efficiency or to synfuels are covered. For automobiles, the issues include the effects of incentives for increased fuel efficiency on the evolution and health of the U.S. auto industry, the possibilities for a highly fuel-efficient car, the safety of small cars, current demand for fuel efficiency in cars, and the prospects for electric vehicles. For synfuels, probable environmental dangers, water constraints, and compatibility of synfuels with existing end uses are considered.

Each separate entry in this chapter is designed to stand alone and generally does not build on other material in the chapter. The chapter is not designed to be read from beginning to end; rather, each reader can turn directly to those comparisons and issues of interest without loss of context or regard for the way the entries are ordered.

WHAT DO OIL IMPORTS COST?

The private U.S. consumer pays the going market price for imported oil, but that is not its only economic cost. In the last decade, the Nation has been forced to pay a substantial additional "premium" because of its strategic dependence on a small number of foreign oil producers. During especially unstable periods, such as the 1973-74 Middle East War and the 1978-79 Iranian Revolution, this import premium payment is highly visible and, when measured in terms of the incremental cost for that segment of demand which clearly exceeds available supplies, it can greatly exceed the actual market price.

It is reasonable to attribute an exceptional premium payment to oil, and not to other imported goods and services, because uninterrupted oil supplies are critical to economic stability (i.e., few substitutes exist at least in the short run) and because the United States has become the prominent importer on the world scene and has assumed major responsibility for protecting world oil trade. No other import constitutes such a vital economic resource that must flow in such a large continuous stream around the world. Although the third quarter of 1981 has witnessed falling oil prices and a modest supply surplus, future shortage risks remain plausible because of the expected longrun depletion of world oil reserves and because of unresolved and potential international conflicts.

The existence of a national premium payment for oil imports can be explained in terms of three economic relationships:

1. the dependence of international price on the quantity of U.S. imports;
2. the loss of U.S. jobs and gross national product (GNP) caused by oil payments abroad and the associated depreciation of the dollar; and

3. the budgetary cost of military outlays and foreign military assistance related to assuring the security of oil imports. These are described below.

Dependence of Price on Quantity Imported

Market price is a good measure of real or total cost when markets are competitive and in a state of stable equilibrium. Neither situation is characteristic of international oil markets, which are dominated by a small number of sellers and buyers in an unstable marriage of short-term convenience. Despite the complexity and unpredictability of this relationship, it seems reasonably clear that raising U.S. oil imports drives price upward and vice versa, simply because any movement by such a prominent importer appears to the rest of the world as a shift in the world demand curve. This positive relationship between quantity imported and price means that the cost of incremental U.S. consumption exceeds current price because the increment makes all future consumption more expensive. Conversely, decrements in U.S. consumption save more money than the marginal reduction in purchases.

Eventually, oil markets may anticipate this price/quantity relationship, but market adjustments may not be smooth. Shocks can be expected, leading to domestic inflation and recession, because international relationships between exporters and importers have become politicized and because significant reductions in oil consumption are difficult to achieve over periods of up to several years due to the long lifetimes of energy-related capital stock and the long leadtime for alternative domestic fuels.

Loss of U.S. Jobs and GNP Caused by Rising Oil Payments and by Potential Supply Interruptions

Oil imports accounted for 26 percent of U.S. payments for imports in 1979, which is about twice the level of the second largest item. Consequently, compared with equivalent rates of growth or decline for other imports, changes over time in oil payments have a relatively large impact on the U.S. balance of trade, and, hence, a relatively large impact on the exchange value of the dollar.

In periods when the dollar is relatively strong, as it has been recently (second half of 1981), it is due in part to declining oil payments. In periods when the dollar is weak, as it was during most of the 1970's and especially after 1975 because of large deficits in merchandise trade, growing oil payments increase selling pressure on the dollar, lowering its foreign exchange value. While this makes U.S. exports more attractive to foreign buyers, export sales may not increase elastically because of stagnant world economy or failure of U.S. goods to meet quality standards. Therefore, market adjustments, including both higher prices and undoubtedly reduced purchases, are forced on U.S. importers.

Furthermore, the declining value of the dollar has relatively little effect on oil imports, again due to the long lifetimes of capital related to oil consumption. Barring economic recession, oil consumption significantly declines only with the slow replacement of capital. Thus, even though rising oil imports or sharply rising oil import prices may be clearly responsible for dollar depreciation, oil consumption may not bear the brunt of the resulting short-term adjustment.

Overall, adjustments in the U.S. balance of payments also affect domestic economic activity. A sharply rising oil import price directly increases domestic inflation while at the same time larger foreign payments can lower total demand for domestic goods and services if, as is likely in the short run, oil exporters do not spend their larger receipts in the United States. This combination of rising inflation and declining total demand puts the Federal Government in a difficult position because corrective policies are contradictory. If control of inflation is the primary objective, sharp oil price increases may force the Government to brake the growth momentum of the national economy or exaggerate downward cycles in order to limit propagation of inflationary pressures.

In addition to oil price shocks, potential supply interruptions of oil imports present the clearest, most direct threat to national economic activity. As discussed above, few good substitutes exist for oil in the short run, so that reduced flow results in lost production and unemployment as soon as stockpiles can no longer make up for the deficit.

The potential premium payment, implied by both unstable oil import prices and supply interruptions, can be illustrated in terms of the 1973-74 shock. In 1974 and again in 1975, real GNP declined by more than a percentage point after having grown at a rate of 5 percent in 1973 and 4 percent in 1972. Although cause and effect in macroeconomics is highly speculative, the losses in 1974 and 1975 are widely believed to have been due in part to the disruption of oil supplies and the associated quadrupling of imported oil prices. If, in fact, real GNP growth had been reduced by just one percentage point by oil-related events, it would have meant a loss of about $15 billion in U.S. production ($1.5 trillion GNP in 1975), which amounts to $6.80 per barrel (bbl) for the 2.2 billion bbl imported that year. The price of oil at that time was about $11.

Military Outlays and Foreign Policy Directions Forced by Oil Import Dependence

Military and foreign policy are predicated on many national objectives, but apparently one very important consideration for the United States is protection of oil supply lines. The cost of such protection cannot be ascertained directly, but current debate over defense budget priorities indicates that the United States intends to develop weapons systems and train personnel in order to be able to fight a war in the Middle East, if necessary.

If 10 percent of estimated 1982 defense outlays were justified to meet military threats to Middle East oil supplies, it amounts to about $18 billion or about $9/bbl for the 2 billion bbl of oil imported (net of exports) in 1981.

Conclusion

The complexity and unpredictability of world oil markets and world oil politics make it difficult to predict the oil import premium over time.* In OTA's judgment, the possible future import premium could range up to $50/bbl. It could be negligible if world demand continues its sharp downward trend and if major new discoveries are made outside the Middle East, but could be much larger than the current price of oil if hostilities break out which cut off most supplies from the Middle East.

A technical analysis must stop short of greater certainty except to indicate that a significant reduction of imports would drive the premium down by reducing the visibility of the United States in world oil markets and by reducing U.S. dependence on supplies from politically unstable countries. In other words, the premium payment for the last barrel of imports is much higher than for the first, and it is the last barrel which would be displaced by domestic synfuels or by higher fuel efficiency in automobiles.

HOW QUICKLY CAN OIL IMPORTS BE REDUCED?

Options for reducing U.S. oil consumption are considered in detail later in the report. Here, the results of those analyses are summarized and the relative contributions that the various options can make to reducing imports over the next two decades are considered.

Table 9 shows the estimated level of imports in the absence of synthetic fuels and automobile fuel-efficiency increases beyond a 1985 level of 30 mpg. This base case also assumes: 1) the Energy Information Administration's (EIA) high oil price future to 1990 for the consumption of oil

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*A number of estimates for both components of the oil import premium are available. For the most detailed discussion of related economic issues and documentation of results from current economic models, see *World Oil*, Energy Modeling Forum, Stanford University, Stanford, Calif., ch. 5 (forthcoming).

Table 9.—Minimum Oil Imports for Base Case (MMB/DOE)

	1980	1985	1990	1995	2000
Stationary demand[a] (no additional measures past 1990)	8.1	7.3	6.4	6.4	6.4
Transportation demand (other than automobiles	4.5	4.7	5.0	5.4	5.7
Automobiles (with 1985 new-car average of 30 mpg, no change thereafter)	4.3	3.6	3.0	2.7	2.7
Sum of demand	16.9	15.6	14.4	14.5	14.8
Domestic production[b]	10.2	8.6	7.6	7.1	7.0
Imports	6.7	7.0	6.8	7.4	7.8

[a] Includes all nonfuel oil uses such as asphalt, petrochemical feedstock, liquefied petroleum gas, etc., which are projected by the Energy Information Administration to total 3.8 MMB/D by 1990.
[b] Oil plus natural gas liquids.

SOURCE: Office of Technology Assessment.

for stationary uses;[1] 2) the transportation petroleum demand (other than for passenger cars) explained in chapter 5; 3) fuel oil demand by stationary uses is held constant after 1990; and 4) the maximum domestic oil production projected by OTA.[2] For 1995 and 2000, the trends of the 1980's for stationary uses of petroleum other than fuel oil have been extrapolated, while holding fuel oil consumption constant at the projected 1990 level. The assumption of constant fuel oil demand for the 1990's was chosen as the base case to help illustrate the importance of eliminating this demand relative to other options for reducing oil imports in the 1990's.

It should be emphasized that a considerable reduction in oil consumption through increased efficiency and fuel switching in the 1980's is already built into the base case. In particular, achieving an average new-car fuel efficiency of 30 mpg by 1985 saves about 0.8 million barrels per day oil equivalent (MMB/DOE) by 1990, relative to 1980 demand;* and conservation and fuel switching in the EIA high oil price scenario reduce oil consumption by 1.7 million barrels per day (MMB/D) in stationary uses by 1990. However, domestic oil production is likely to drop by at least 2.6 MMB/D during this same time period,[3] thereby nullifying any reduction in oil imports from these measures alone.

Table 10 shows the various reductions in oil consumption that may be achieved beyond the base case. These include contributions from further conservation and fuel switching in stationary uses, increased automobile fuel efficiency beyond a 1985 level of 30 mpg, electric vehicles (EVs), and synfuels. Each of the areas where additional oil savings are possible is discussed below.

By 1990, stationary demand for residual and distillate *fuel oil* is 2.6 MMB/D in the base case.* As explained in chapter 7, a combination of cost-effective conservation measures and switching to natural gas and electricity can eliminate this stationary fuel oil demand without a need to increase gas production or electric generating capacity. How much of this potential actually is reached will depend on such things as individual decisions about conservation investments and

Table 10.—Contributions to the Reduction of Oil Imports Beyond the Base Case (MMB/DOE)

	1980	1985	1990	1995	2000
Conservation and switching in stationary applications	0	0	0	0.8[a]-1.3	1.5[a]-2.6
Increased automobile fuel efficiency beyond 1985 average of 30 mpg	0	0-0.1	0.1-0.5	0.3-1.0	0.6-1.3
(Average new-car efficiency, mpg[b])	(23)	(30-37)	(36-49)	(40-63)	(45-79)
Electric vehicles	0	0	0	0	0-0.1
Synthetic transportation fuels:					
Fossil	0	0-0.1	0.3-0.7	0.7-1.9	1.3-4.5
Biomass	0	(c)	0-0.3	0-0.6	0.1-1.0
Total	0	0-0.2	0.4-1.5	1.8-4.8	3.5-9.5

[a] Energy Information Administration forecast.
[b] 55 percent EPA city/45 percent EPA highway test cycles.
[c] Less than 0.05 MMB/D.

SOURCE: Office of Technology Assessment.

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[1] Energy Information Administration, U.S. Department of Energy.

[2] *World Petroleum Availability: 1980-2000—Technical Memorandum*, OTA-TM-E-5 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1980).

*The fuel saved in cars is 0.9 million barrels per day (MMB/D), but the assumed increase in transportation needs raises consumption in other types of transportation by 0.1 MMB/D.

[3] *World Petroleum Availability: 1980-2000—Technical Memorandum*, op. cit.

*The remainder of the 6.4 MMB/D of stationary oil use includes asphalt, petrochemical feedstocks, liquefied petroleum gas,and refinery still gas.

availability of transmission and distribution systems. The most recent projection of EIA provides a reasonable lower bound on the reduction in fuel oil that can be achieved during the 1990's.

The range of potential savings from increased automobile fuel efficiency corresponds to the low and high estimates derived in chapter 5 and different assumptions about relative future demand for small-, medium-, and large-sized cars, i.e., 1) no shift to smaller cars and pessimistic assumptions about efficiency increases from automotive technologies, and 2) a substantial shift to smaller cars and optimistic assumptions about the technologies. By 2010, automobiles containing the average technology of 2000 would have replaced most cars on the road and the savings, relative to the base case, would be 0.8 to 1.7 MMB/D (2.3 to 3.2 MMB/D relative to 1980 demand).

It should be emphasized that average new-car fuel efficiencies shown in table 10 do *not* represent a technical limit to what can be achieved. In any given year, cars with higher (and lower) mileages than those shown would be produced and sold.* Rather, the mileage ranges correspond to what OTA considers to be feasible through a variety of technological improvements.

If a very strong demand for fuel-efficient cars develops, e.g., as the result of continued large oil price increases, consumers may be willing to accept poorer performance or pay the added cost in order to achieve higher fuel efficiency. In this case, the estimated average fuel efficiency shown for 2000 in table 10 could be achieved by the mid-1990's.

The contribution from EVs was calculated by assuming that 0 to 5 percent of passenger automobiles would be electric by 2000, growing linearly from 0 percent at 1985. The savings from EVs is relatively small, however, because of the relatively low consumption of petroleum by automobiles (1.3 to 2.1 MMB/DOE in 2000) and the fact that EVs would be a substitute for the most fuel-efficient cars.

The final category in table 10, synthetic fuels, must be considered carefully to ensure that only the synthetic fuels production that displaces oil is included and technical difficulties are accounted for. To derive the low estimate of synfuels contributions, it is assumed that by the time synthetic fuels become available, the only remaining stationary uses of petroleum are for chemical feedstocks, asphalt, petroleum coke, still gas, and liquefied petroleum gas (LPG). Since these products cannot now be economically converted to transportation fuels, the low estimate in table 10 assumes that their replacement by synthetic fuels (synthetic gas) would not result in additional transportation fuels.* In addition, poor performance of the first round of synfuel plants is assumed, limiting production until the early to mid-1990's. As a consequence of this, the low synfuels production scenario from chapter 6 is used in the table 10 low estimate.

A more optimistic scenario is possible if it is assumed that market or other forces strongly favor the production of transportation fuels over synthetic fuel gases and that half of the synthetic gas** plants projected in chapter 6 actually are built to produce synthetic transportation fuels. With these assumptions and the high scenarios presented in chapter 6, one arrives at the upper estimate for oil displacement by synfuels shown in table 10. The high estimate, however, represents a vigorous dedication to synfuels production and what might be termed near "war mobilization" development of the industry.

The range of oil savings from each of these sources is shown in figure 4, alongside the import levels calculated in the base case. As can be seen, under the most favorable circumstances it is technically possible to eliminate oil imports by 2000. However, if domestic oil production[5] is below that shown in table 9 and if only the low estimates of table 10—or even only the low esti-

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*For example, up until January 1981, the 1981 model new-car fuel efficiency of cars sold averaged slightly less than 25 mpg, but if the most fuel-efficient cars in each size class had been bought, the average would have been about 33 mpg.[4]

[4] Derived from data in J. A. Foster, J. D. Murrell, and S. L. Loos, "Light Duty Automotive Fuel Economy . . . Trends Through 1981," U.S. Environmental Protection Agency, SAE paper No. 810386, February 1981.

*LPG can, however, be used directly in appropriately modified automobiles.

**Excluding biogas from manure, which would be used principally on the farms where it is produced.

[5] *World Petroleum Availability: 1980-2000—Technical Memorandum,* op. cit.

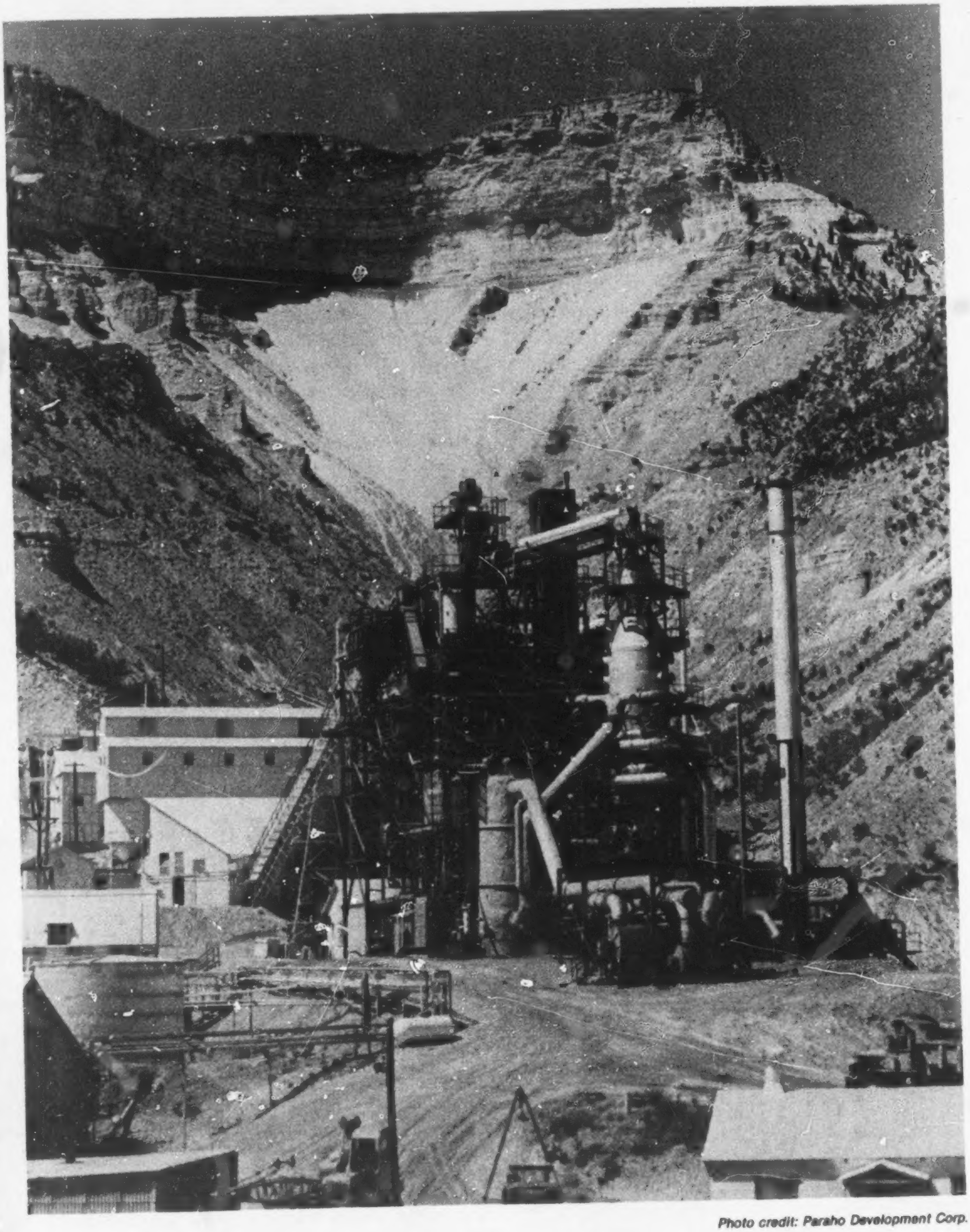
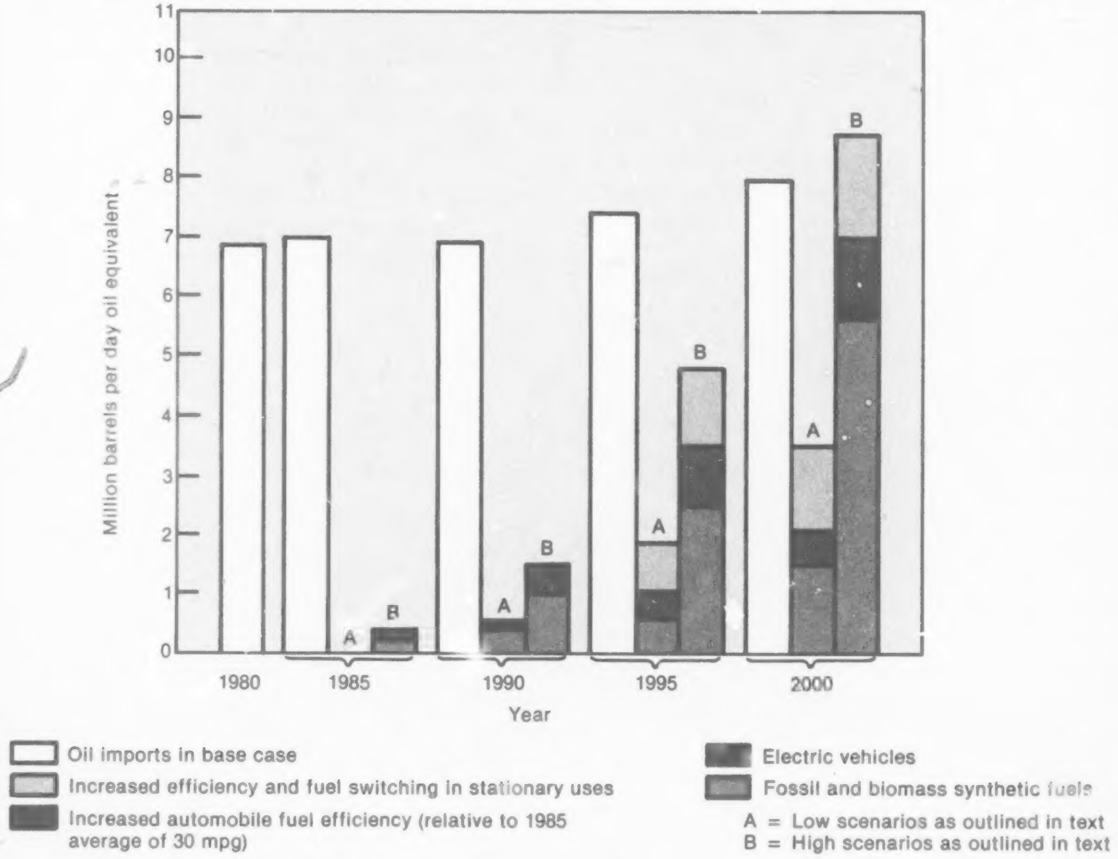


Photo credit: Paraho Development Corp.

The Paraho Semiworks Oil Shale Unit at Anvil Points, Colo.

Figure 4.—Comparison of Base Case Oil Imports and Potential Reductions in These Imports



SOURCE: Office of Technology Assessment.

mate for synfuels—are reached, then it is quite unlikely that oil imports can be eliminated before sometime well into the first decade of the 21st century.

Although the large number of noteworthy uncertainties make an exact determination of the course of oil imports impossible, several conclusions can be drawn.

First, increased efficiency and fuel switching in buildings and industry are extremely important for the reduction of oil consumption. Although much of the potential in this area will be achieved through market forces by 2000 under the high oil price scenario of EIA, implementing the necessary changes at an earlier date could significantly reduce oil imports before 2000. For example, fully implementing the potential for reducing stationary uses of fuel oil by 1990 would save about 15 billion bbl of oil imports or $600 billion (at an average of $40/bbl) for the imports during the period 1981-2000.

Second, synthetic fuels development has approximately the same importance as the conservation and fuel switching options but its contribution to reduced imports will not be as large until at least the late 1990's. Further, if a large part of the synfuels is used as a substitute for increased efficiency and for conventional fuel switching in stationary uses or as a substitute for petroleum products not readily converted to transportation fuels, elimination of oil imports is likely to be delayed.

Third, increases in automobile fuel efficiency beyond a 1985 average of 30 mpg could reduce automobile fuel consumption 20 to 50 percent (0.6 to 1.3 MMB/D) by 2000 below the fuel consumption of a 30-mpg fleet. In addition, because fuel efficiency increases in automobiles (to and beyond 30 mpg) could reduce the automobile's share of transportation fuel needs from 50 percent (in 1980) to 20 to 25 percent (in 2000), it is likely that efficiency increases in various nonautomobile transportation uses beyond those assumed in the base case could also make significant contributions to reducing transportation fuel needs. This option has not been analyzed by OTA.

In summary, it probably will be necessary to implement fully all of the options for reducing oil consumption if one wants to eliminate net oil imports before the first decade of the next century. This will require full implementation of charges needed for increased efficiency in all uses of oil and fuel switching in stationary uses, as well as directing synfuels production to transportation fuels.

WHAT ARE THE INVESTMENT COSTS FOR REDUCING U.S. OIL CONSUMPTION?

Introduction

Investment costs are an important consideration when comparing alternatives for reducing U.S. oil consumption. OTA's analysis indicates that synfuels production, increased fuel efficiency in automobiles, and conservation and fuel switching in stationary uses of oil all will require investments of the same order of magnitude for comparable reductions in oil consumption in the 1990's; whereas, synfuels production appears to require larger investments than the other alternatives for the 1980's. Uncertainties in the cost estimates as well as the fundamental differences in the nature of the investments are too large, however, to allow a choice between approaches on this basis alone.

In order to compare investment costs, they have been expressed as the investment needed to either produce or save 1 barrel per day oil equivalent* of petroleum products. This method was chosen in order to avoid problems that arise when comparing investments in projects with different lifetimes and for which future oil savings may be discounted at different rates.** In addition, from a national perspective the per unit investment cost is important in that it is the parameter used in the aggregate to make choices among competing investments. Conventional oil and gas exploration are considered first to provide a reference point. Following this, OTA's estimates for the investment costs for increased automobile fuel efficiency, EVs, synfuels, and increased efficiency and fuel switching in stationary uses are discussed briefly.

Conventional Oil and Gas Production

Two estimates of recent investment costs for conventional oil and gas exploration and development in the United States are shown in table 11. The data in this table were developed from estimates of the annual investments in oil, gas, and natural gas liquids exploration and development per barrel of increased proven reserves of these fuels (corrected for depletion). These latter estimates were then converted to investments for an increase of 1 barrel per day (bbl/d) of production (corrected for depletion) using the 1980 ratio of crude oil reserves to crude-oil production and assuming an 8 percent refining loss. The ratio of reserves to production for natural gas was not used because price controls on natural gas tend to inflate this ratio and thus the estimated costs; and investments for oil exploraton and development were not separated from those for natural gas because there is no practical way to do so.

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*One barrel of oil equivalent = 5.9 MMBtu.

**It does not, however, avoid the problem that the different parties making the investments will have fundamentally different constraints on and perspectives about these investments and thus will react quite differently in the face of investments of the same size.

Table 11.—Estimated Investment Costs for Conventional Oil and Natural Exploration and Development

Year	Estimated investment cost (thousand 1980 dollars per barrel per day of petroleum production[a])	
	Estimate A[b]	Estimate B[c]
1974	13	15
1975	17	19
1976	20	17
1977	22	20
1978	29	18
1979	31	57[d]
1980	Not available	39[e]
Extrapolated to 1985[f]	53	49

[a] Assumes 8-percent refining loss and a 1980 ratio of crude oil reserves to production of 3.07×10^3 barrels of reserves per barrel per day production. If EIA data for petroleum reserves are used, the figures are increased by about 10 percent.

[b] Investment cost per barrel of increased reserves from A. T. Guernsey, "Economics of Domestic Crude Oil and Natural Gas Exploration and Development 1959-1976," December 1977, and "1977 and 1978 Addendum," June 1979. Prepared for Exploration and Production Department, Shell Oil Co., Houston, Tex.; and W. C. Hamber, Manager, Forecasting, Exploration and Production Economics, Shell Oil Co., Houston, Tex., private communication, Nov. 11, 1981.

[c] Investment cost per barrel of increased reserves for the 26 major energy companies in the United States calculated for OTA by John Rasmussen, Economics and Statistics, Energy Markets and End Use, EIA, October 1981, based on EIA and American Petroleum Institute data. See also "Performance Profiles of Major Energy Producers 1979," EIA, U.S. Department of Energy, DOE/EIA-0206(79), July 1981.

[d] This estimate is anomalously high due to downward revision of estimated reserves by Texaco during the year and because Ashland Oil sold some of its crude oil reserves to a company not included in a sample of 26 major energy companies.

[e] This estimate may be low because petroleum reserve additions are overstated due to the purchase of Texas Pacific Oil & Gas (not one of the 26 major companies included in the calculation) by Sun Oil Co. (one of the 26 major energy companies included in the calculation).

[f] Based on least squares fit of 1974-80 data, exclusive of 1979 data in estimate B. Correlation coefficient is 0.985 for estimate A and 0.82 for estimate B.

SOURCE: Office of Technology Assessment.

There are significant uncertainties in these estimates due to numerous anomalies in the data, some of which are detailed in footnotes to table 11, and because the ratio of reserves to production changes with market prices, production techniques (e.g., enhanced oil recovery), and the nature and quantity of reserves. Nevertheless, these data do indicate that it is reasonable to expect costs of $50,000/bbl/d or more for conventional petroleum exploration and development by the mid-1980's if recent cost trends continue.

Automobile Fuel Efficiency

OTA's estimates of the investment plus associated product development costs for increased automobile fuel efficiency are shown in table 12. There are notable technical, accounting, and market uncertainties associated with this type of cost analysis, however.

The estimates in table 12 were derived by first estimating the efficiency gains that can reasonably be expected over time from various changes in the automobile system. They are based on both published estimates and OTA's analysis. The rates at which these technologies may be incorporated into new cars were then estimated and resultant schedules for capital turnover derived. Next, the investment cost calculations were based on published estimates for the cost of replacing the applicable capital equipment (e.g., facilities for producing a new engine or transmission, etc.). The actual investment cost and resultant fuel efficiency increases, however, will depend on a number of factors specific to individual production plants (and their future evolution), the way various production tradeoffs are resolved, and the results of future product development programs.

In addition to capital investment, development costs have been included as part of the investment necessary to produce modified vehicles. During the 1970's, domestic auto manufacturers' R&D (mostly development) costs averaged from 40 to 60 percent of their capital investments.[6] In table 12, development costs are assumed to be 40 percent of the capital investment allocated to fuel efficiency (see below), but the actual costs of developing the technologies for producing more efficient cars at minimum cost are highly uncertain.*

Beyond the uncertainties in the investment and development costs, there is the problem of determining what fraction of the investments should be ascribed to fuel efficiency. This arises because some of the investments can be used not only to increase fuel efficiency, but also to make other

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[6] G. Kulp, D. D. Shonka, and M. C. Halcomb, "Transportation Energy Conservation Data Book: Edition 5," Oak Ridge National Laboratory, ORNL-5765, November 1981.

*It should be noted that R&D costs are not included for synfuels because several essentially identical synfuels plants could be constructed with little additional R&D costs beyond those needed for the first plant, whereas product and process development are necessary for each major change in automobiles.

Table 12.—Capital Investment Allocated to Fuel Efficiency Plus Associated Development Costs

			Average capital investment plus associated development costs[b]	
Time of investment	Mix shift	New-car fuel efficiency at end of time period[a] (mpg)	Thousand 1980 dollars per barrel per day oil equivalent of fuel saved[c]	1980 dollars per car produced[d]
1985-1990	Moderate[e]	38-48	20-60[g]	50-190[g]
	Large[f]	43-53		
1990-1995	Moderate[e]	43-59	60-130[g]	70-180[g]
	Large[f]	49-65		
1995-2000	Moderate[e]	51-70	50-150[g]	50-150[g]
	Large[f]	58-78		

[a] EPA rated 55/45 percent city/highway fuel efficiency of average new car.

[b] Development costs assumed to be 40 percent of capital investment allocated to fuel efficiency (see text). One barrel of oil equivalent contains 5.9 MMBtu.

[c] Averages are calculated by dividing average investment for technological improvements by fuel savings for average car at end of time period relative to average car at beginning of time period. The resultant average cost per barrel per day is lower than a straight average of the investments for each car size because of mathematical differences in the methodology (i.e., average of ratios v. ratio of averages) and because extra fuel is saved due to demand shift to smaller cars. The averaging methodology used is more appropriate for comparisons with synfuels because it relates aggregate investments to aggregate fuel savings. It should be noted that the cost of adjusting to the shift in demand to smaller-sized cars is not included. Only those investments which increase the fuel efficiency of a given-size car are included.

[d] Assuming investment is used to produce cars for 10 years, on the average.

[e] Moderate shift in demand to smaller cars. Percentage of new cars sold in each size class are:

Year/size class	*Large*	*Medium*	*Small*
1985	35	60	5
1990	25	60	15
1995	20	55	25
2000	15	50	35

[f] Large shift in demand to smaller cars. Percentage of new cars sold in each size class are:

Year/size class	*Large*	*Medium*	*Small*
1985	15	75	10
1990	5	65	30
1995	5	45	50
2000	5	25	70

[g] Within uncertainties, the costs are the same for both mix shifts.

SOURCE: Office of Technology Assessment.

changes in the car.* The cost allocation problem associated with multipurpose investments is well known in accounting theory, and there is no fully satisfactory solution to it.[7]

For table 12, it was assumed that 50 percent of the cost of engine and body redesign, 75 percent of the cost of most transmission changes, and 100 percent of the cost of advanced materials substitution and energy storage and automatic engine cutoff devices should be allocated to fuel efficiency. This results in between 55 and 80 percent of the investments being allocated to fuel efficiency, depending on the time period and scenario chosen. For further details on how this and other problems in estimating the cost of fuel efficiency were resolved, see chapter 5.

During the period 1985-2000, total capital investments in changes associated with increasing fuel efficiency (i.e., allocating 100 percent of the multipurpose investments to fuel efficiency) could average $2 billion to $5 billion per year, depending on the number of new cars sold and the rate at which fuel efficiency is increased. However, if one deducts the cost of changes that would have been made under "normal" circumstances,* the added capital investment needed to achieve the lower mpg numbers in table 12 would be $0.3 billion to $0.7 billion per year. The higher mpg numbers in table 12 would require added capital investments (above "normal") of $0.6 billion to $1.5 billion per year. Adding 40 percent of the capital investment for development costs results in added outlays of $0.4 billion to $0.9 billion per year and $0.8 billion to $2 billion per year for the low and high scenarios, respectively.

A detailed examination of the scenarios presented in chapter 5 shows that a 1990 new-car average fuel efficiency of 35 to 45 mpg (depending on the proportion of small, medium, and large cars sold) probably can be achieved with what is termed here "normal" rates of capital turnover. However, the validity of this conclusion and of the above incremental investment and development cost estimates will depend on market demand for fuel efficiency, and, in OTA's judgment, there is no credible way to predict future market demand for fuel efficiency.

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*For example, automobile designs with low aerodynamic drag may be preferred by consumers on esthetic grounds; front wheel drive may be introduced to improve traction and increase interior volume; microprocessor control of carburetion or fuel injection, spark advance, exhaust gas recirculation, and other operating conditions can be used to reduce exhaust emissions, improve performance, and enable the use of lower octane fuels; continuously variable transmissions may be introduced to produce smoother acceleration and improve performance. These and many other changes can also be exploited to improve fuel efficiency.

[7] A. L. Thomas, "The Allocation Problem in Financial Accounting Theory," American Accounting Association, Sarasota, Fla., 1969, pp. 41-57, and A. L. Thomas, "The Allocation Problem: Part Two," American Accounting Association, Sarasota, Fla., 1974.

*Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced materials substitution.

Electric Vehicles

Use of EVs more nearly approximates synfuels than increased automobile fuel efficiency, in that EVs involve switching from conventional oil to another energy source rather than reducing energy consumption. Consequently, the costs (per barrel per day of oil replaced) for EVs are included in table 13 with synfuels. As shown in table 13, the costs for EVs appear to be significantly higher than for the various synfuels options, due to the high purchase price of the vehicle (relative to a comparable gasoline-fueled car) and the fact that EVs would be replacements for relatively fuel-efficient cars (because of an EVs limited size and acceleration). Furthermore, if batteries must be replaced at regular intervals and the cost of this is included as an investment cost, the total investment per barrel per day rises dramatically.

Synfuels

The best available estimates for the investment costs for various liquid synthetic transportation fuels are shown in table 13. Because of uncertainties in the cost estimates, no meaningful intercomparison among synfuels on the basis of cost is currently possible. In addition, as discussed in chapter 6, the final investment in synfuels is likely to be different from these estimates. As the processes approach commercial production, they will be revised as costs to overcome problems encountered in demonstration units are determined. Construction costs will inflate at an unknown rate relative to general inflation. And delays during construction due to such possibilities as lawsuits, strikes, late delivery of construction materials, or other causes can increase the investment cost. In sum, current investment estimates provide a very tentative guide to what synfuels plants constructed in the 1990's will cost. In addi-

Table 13.—Investment Cost for Various Transportation Synfuels and Electric Vehicles

	Thousand 1980 dollars per barrel per day oil equivalent to end users				
	Shale oil	Methanol from coal	Coal to methanol and Mobil methanol to gasoline	Direct liquefaction	Electric vehicle
Mining	(Included in conversion plant)	4-15	4-15	4-15	5-19
Conversion plant	49-73[a]	47-93[a]	53-110[a]	67-100[a]	0-69[b]
Refinery	0-10[c]	0	0	4-22[d]	0
Distribution system	0	0-2[e]	0	0	0
End use	0	0-11[f]	0	0	320-390[g]
Total	49-83	51-121	57-125	75-137	325-478

[a] Range of investments in ch. 6 plus possible 50-percent cost overrun and assuming plants operate at 90 percent of rated capacity.

[b] Upper limit corresponds to case where new coal-fired electric generating capacity would be needed. That is not currently the case, however.

[c] Upper limit corresponds to a dedicated refinery.

[d] Upper limit from UOP and Systems Development Corp., "Crude Oil v. Coal Oil Processing Comparison Study," DOE/ET/03117, TR-80/009-001, November 1979. Inflated by 12 percent to reflect 1980 cost. Assumes a refinery dedicated to conversion facility. Lower limit from "SRC-II Demonstration Project, Phase Zero, Task No. 3, Market Assessment Transportation Fuels From SRC-II Upgrading," Pittsburgh and Midway Coal Mining Co., prepared for U.S. Department of Energy, July 31, 1979. Assumes only upgrading of liquid for use as feedstock in an existing refinery.

[e] Upper limit assumes that half of capacity must use newly constructed or expanded facilities, as follows: 500-mile pipeline at $1 million per mile, 500,000 bbl/d capacity; tank truck (9,200 gal) costing $90,000, 10 runs per week; storage tanks and pumps costing $700/bbl/d of throughput.

[f] Upper limit assumes new engine design costing $540 million for a 500,000 car per year factory; 0.15 capital recovery factor; replacing car consuming 250 gal of gasoline/yr. Beyond the initial investment in new engine production facilities, the investments are the same as for a gasoline engine, making the added investment zero, relative to gasoline vehicles.

[g] Assumes an electric vehicle costs $3,000 more than a comparably performing gasoline-powered car and the electric vehicle replaces 8,000 to 10,000 miles/yr that would have been driven in a 60-mpg gasoline- or diesel-fueled car. If batteries must be replaced every 10,000 miles (nine times over life of car) at a cost of $2,000 each time, the total investment becomes $2.7 million/bbl/d replaced. These calculations assume that no oil is used in the electric generating facilities; however, if oil is used to generate part of the electricity, the investment costs per barrel per day of oil displaced grow rapidly.

SOURCE: Office of Technology Assessment.

tion, they most likely represent a lower limit of the synfuels investment costs.*

Stationary Uses of Petroleum

OTA has also considered the costs of conservation and fuel switching in stationary uses of oil, although not in the same detail as for synfuels and increased automobile fuel efficiency. The major candidates are the residual and distillate fuel oils still used in stationary applications after 1990. Other stationary uses of petroleum—asphalt, petrochemical feedstock, still gas, and liquefied petroleum gas (LPG)—were not considered to be major potential supplies of increased transportation fuels. Although LPG can technically be used as a transportation fuel, and petrochemical feedstocks can be replaced by synthesis gas from coal, a preliminary analysis indicates that the fuel oils are more economically attractive alternatives for increasing supplies of transportation fuels in most cases.

OTA's estimates for the investment costs of fuel switching and increased energy efficiency in stationary uses during the 1990's are shown in table 14. Although only single numbers are shown, in fact there will be a range of costs depending on development costs for new energy supplies, installation costs for end-use equipment, the extent of changes needed at oil refineries, and variations in conservation investments. Of the fuel switching options the range is narrowest for fuel switching to electricity because of the fairly well-defined cost of producing electricity from coal and largest for fuel switching to natural gas because of differences in the cost of developing various unconventional gas supplies.

In deriving the numbers in table 14, it was assumed that the lower cost opportunities for fuel switching and conservation would already have been carried out by 1990. To the extent that this does not occur, the per-unit investment cost estimates for the 1990's would be lowered somewhat. Also, increased end-use efficiency of electricity for heat and hot water would reduce the investment needed for electric powerplants; and if large supplies of relatively inexpensive gas are found, fuel switching to gas could be a very attractive option, in terms of capital investment. Because of these uncertainties and site-specific differences in installation costs, one cannot clearly choose among the alternatives on the basis of investment costs alone. All of the options to eliminate stationary fuel oil use seem to require the same order of magnitude of investments.

Conclusion

Three principal conclusions emerge from OTA's analysis of investment costs for the various ways of reducing oil consumption. First, there is a great deal of uncertainty about investment costs due to technological unknowns, lack of experience, and site-specific cost differences.* Second,

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*Decisions about whether and how quickly to proceed with investments in synfuels production, however, will be strongly influenced not only by estimated costs but by corporate strategy.

*The situation is further complicated by the different nature of the investments. Synfuel plant construction requires large investments over a number of years before any product is sold. Auto industries tend to make incremental changes in capital stock, with the sum of several such investments sometimes costing more than one abrupt changeover in capital stock. Investments in fuel switching and conservation are paid back through future fuel cost savings rather than product sales.

Table 14.—Estimated Investment Cost of Fuel Switching and Conservation in Stationary Petroleum Uses During the 1990's

	Thousand 1980 dollars per barrel per day of oil replaced or saved				
Investment at	Conversion to natural gas	Conversion to electricity	Conversion of boilers from residual fuel oil to coal		Increased efficiency and fuel switching
End use equipment	24	32	37	(51)[a]	88
New production of fuel	90	78[b]	16[c]	(22)[a]	0
Total	114	110	53	(74)[a]	88

[a] The number in parenthesis is corrected for the 72-percent efficiency of refining residual fuel oil and is the investment per barrel per day of resultant distillate oil produced from the residual oil.

[b] Construction of coal-fired powerplant ($74,000) plus new coal mining ($4,400).

[c] Modification of refineries to upgrade residual oil to distillate fuels, $14,000, and increased coal production, $2,000. The refinery modification is based on data presented in ch. 6, assuming that 0.6 MMB/D of domestically produced residual oil is already being upgraded in 1990.

SOURCE: Office of Technology Assessment.

even if more certain cost data were available today, different inflation rates in different sectors of the economy or modest technical developments could change any conclusions about relative costs by the 1990's. Finally, once the initial investments to reduce oil consumption have been made, the annual capital investment needed to maintain all aspects of liquid fuel production and use will depend on the level of fuel efficiency actually achieved. In particular, high levels of efficiency in end uses will require lower levels of annual capital investment.

Box A.—Consumer Cost of Increased Automobile Fuel Efficiency

For the purposes of this section, the consumer cost of increased fuel efficiency was defined to be the added cost of producing a more fuel-efficient car (relative to an otherwise comparable but less efficient car) per gallon of fuel saved by using the more efficient vehicle. The added cost of producing more fuel-efficient cars will depend not only on the investments needed to change automobile production facilities and the production volumes, but also the resultant changes in the variable costs[*] of production, such as changes in materials and labor costs.

As discussed on page 75, the capital investments that are needed to increase fuel efficiency also produce other changes in automobiles; and allocation of costs among fuel efficiency and the other changes is somewhat arbitrary. In addition, if market demand for fuel efficiency is strong, many changes that increase fuel efficiency would be incorporated into the normal capital turnover of the industry. For the purpose of calculating consumer costs, however, essentially the same approach was taken as with the investment cost estimates. The fraction of investments allocated to fuel efficiency are the same as for the investment costs per barrel per day of fuel saved; and only the average costs per average gallon saved have been calculated—relating each 5-year period to the previous 5-year period —rather than compounding errors by assuming some market-driven scenario as a point of reference.

In addition, it was assumed that production volumes are sufficiently large so that there are no significant diseconomies from small-scale plants or losses from underutilized facilities. Weak demand for fuel efficiency and/or for new cars in general could of course result in additional costs of this sort.

A key factor in consumer costs is the change in variable costs associated with producing more fuel-efficient vehicles. Variable cost estimates, however, are generally proprietary and can vary considerably from one company to another. Furthermore, changes in variable costs with increased fuel efficiency will depend, to a large extent, on the success of efforts to develop production technologies that can hold down production costs. Some of the uncertainties in variable cost changes are discussed below, followed by illustrative examples of plausible consumer costs for increased fuel efficiency.

Some changes that increase fuel efficiency will lower variable costs; some will increase some variable costs while lowering others; and still other changes are likely only to increase variable costs.[*] However, factors which are only peripheral to the nature of the technology incorporated in the car often dominate the change in variable costs. These factors include: 1) the existing nature and layout of equipment in the plant being modified to produce the new car, 2) various specific production decisions (e.g., which of various processes is used in manufacturing a component, what equipment will be modified, what will be the production volume), and 3) the success of developing new, lower cost procedures for producing a component and assembling it in the vehicle. In other words, the net change in variable costs depends not only on the nature of the new technology and the way it is produced, but also on the path the manufacturer has chosen to evolve from the current production facilities and configurations to those needed to produce the more advanced technol-

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[*] Variable production costs are those that vary in proportion to the number of units produced as opposed to fixed costs such as capital charges.

[*] For example, reducing automobile size and weight by reducing the quantity of materials reduces variable costs. Switching to lighter weight materials has the side effect of reducing the needed size of axles, auto frame, etc., which reduces costs; but the higher cost of the new material and increased difficulty of handling that material (e.g., molding, casting, welding, finishing, painting, heat treating) can increase variable costs. Similarly, producing a more efficient engine may enable reduction in engine size, number of cylinders and complexity of the pollution control equipment, which reduces costs; but the need for more precise machining and possibly added equipment (e.g., turbochargers) can raise the variable costs. Finally, changes such as going from a three-speed transmission to a four-speed, five-speed, or continuously variable transmission are likely to increase variable costs because of increased complexity and materials and processing requirements.

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ogy. Furthermore, as with capital investment, there is the problem of deciding what fraction of an increase in variable costs should be ascribed to fuel efficiency. Because of these problems and ambiguities, anything more than a brief overview of the range of possibilities would not be justified.

Various recent estimates of variable cost changes can serve to illustrate the effect of this component on the overall consumer cost of producing more fuel-efficient cars. For example, successful development of production techniques and continued market pressure on automobile companies could hold down production costs so that more fuel-efficient cars can be produced without any large change in manufacturing variable costs. Although some costs will go up, others will drop and the net effect will be little or no change.[1] On the other hand, data presented in a recent analysis based on proprietary automobile industry estimates indicates a substantial increase in variable costs.[2] The apparent increase in variable costs ranges from 60 to 230 percent and averages 170 percent of the costs associated with the capital investments (capital charges) during the period 1985-2000.

To illustrate the effect of this range of variable costs on the ultimate cost to the consumer, a series of calculations were made in table 15. It is assumed that the consumer does not discount future fuel savings and that each car is driven 100,000 miles over its lifetime. The range is calculated by first assuming that the increase in variable costs is negligible, and second that it is twice the capital charges allocated to fuel efficiency (see p. 76). The apparent consumer cost per gallon of fuel saved would be about 2.5 times as large as the numbers shown if the consumer discounts future fuel savings at 25 percent per year.[*] Similarly, the apparent cost per gallon of fuel saved will decrease if the car is driven more than 100,000 miles and increase if the car is driven less than that.[**]

As these examples illustrate, the consumer cost of increased automobile fuel efficiency can vary over a wide range. The cost will depend not only on technical developments and the success automakers have at holding down production costs, but also on consumers' perceptions and accounting procedures, which change with time. As a result, accurate consumer costs probably cannot be derived until production techniques have been developed and proven in practice and market preferences of consumers can be determined.

Table 15.—Plausible Consumer Costs for Increased Automobile Fuel Efficiency Using Alternative Assumptions About Variable Cost Increase

Time period	Mix shift[b]	Average fuel efficiency at end of time period (mpg)	Consumer cost[a] ($/gal gasoline saved): Assuming no variable cost increase relative to 1985 variable costs of production	Consumer cost[a] ($/gal gasoline saved): Assuming variable cost increase equal to twice the capital charges
1985-90	Moderate	38-48	0.15-0.40[c]	0.40-1.10[c]
	Large	43-53		
1990-95	Moderate	43-59	0.35-0.85[c]	1.10-2.80[c]
	Large	49-65		
1995-2000	Moderate	51-70	0.30-0.95[c]	0.90-2.80[c]
	Large	58-78		

[a] Assumes capital charges of 0.15 times capital investment allocated to fuel efficiency, life cycle costing, and car driven 100,000 miles during its lifetime.
[b] See table 12 for definitions of mix shifts.
[c] Within the uncertainties the costs are the same for each mix shift.
SOURCE: Office of Technology Assessment.

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[1] Richard L. Strombotne, Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safety Administration, U.S. Department of Transportation, private communication, 1981.

[2] Richard H. Shackson and H. James Leach, "Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete With OPEC Oil," Energy Productivity Centr, Mellon Institute, Arlington, Va., interim report, Aug. 18, 1980. Variable cost changes were deduced from the estimates of capital investment and changes in consumer costs by assuming an annual capital charge of 15 percent of the investment and deducting this capital charge from the consumer cost estimates.

[*] In other words, the consumer values next year's fuel savings 25 percent less than this year's; savings that will occur during the year after next are valued 25 percent less than next year's, and so on.

[**] Although the person who buys a new car is unlikely to own it for the full 100,000 mile life of the car, the resale value of a more expensive car is also likely to be higher. The cost of a more fuel-efficient car will, in practice, depend on the difference between the purchase and (later) resale price of that car, relative to a less fuel-efficient one. Once the car has been sold and resold several times and finally junked, however, the total cost to all owners per gallon of fuel savings will depend on how far the car has been driven in total.

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Box B.—Consumer Cost of Synfuels

The consumer cost of synthetic transportation fuels will depend on a number of factors. The most important of these are the actual capital investment needed to build the synfuels plant, the way plant construction is financed, the required return on investment, the cost of delivering the fuel to the end user, and the end-use efficiency of the synthetic product. For the first generation of synfuels plants, the cost of producing the synfuel will also depend critically on plant performance, specifically the amount of time the plant is operated below its rated capacity due to the technical problems. (See ch. 6 for a more detailed sensitivity analysis.) Depending on assumptions about these factors, one can derive a wide variety of consumer costs.

Table 16 shows two sets of consumer costs for various fossil synfuels. These costs are based on the best available investment and operating cost estimates and assume no cost overruns, good plant performance (90 percent of rated capacity), a 10-percent real return on equity investment* and two financing schemes: 100-percent equity financing and 75/25 percent debt**/equity financing. Figure 5 shows how these con-

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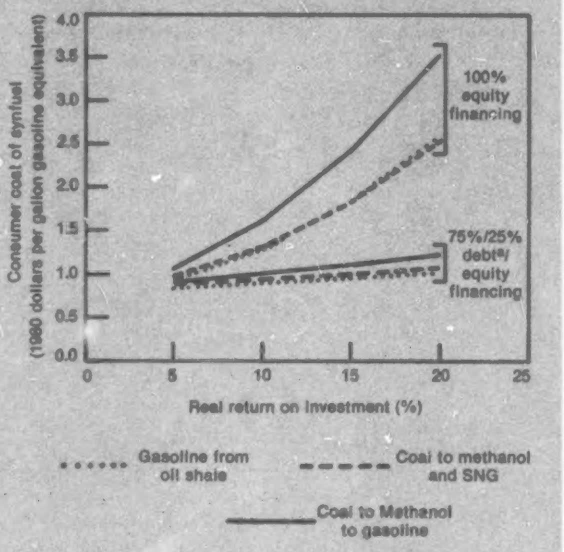
*In other words, a return on investment that is 10 percent higher than general inflation.

**The debt must be project-specific, i.e., the money is loaned for the specific project and is not general debt capital whose payback is guaranteed by other company assets.

Figure 5.—Consumer Cost of Selected Synfuels With Various Aftertax Rates of Return on Investment



[a] 5% real interest rate on debt

SOURCE: Office of Technology Assessment.

Table 16.—Estimated Consumer Cost of Various Fossil Synfuels Using Two Financing Schemes

	Cost of synfuel delivered to end user[a] ($/gallon gasoline equivalent)	
Liquid transportation fuel	100% equity financing[b]	75% debt, 25% equity financing[c]
Reference cost of gasoline from $32/bbl crude oil	1.20	
Shale oil	1.30	0.90
Methanol from coal	1.30[d] (1.10)[e] 1.60[f] (1.30)[e]	0.95[d] (0.80)[e] 1.10 (0.90)[e]
Coal to methanol with Mobil methanol to gasoline	1.25[d] 1.60[g]	0.80[d] 1.00[g]
Coal to gasoline via Fischer Tropsch Synthesis	1.30[d]	0.85[d]

[a] Assumes $0.20/physical gallon delivery charge and service station mark-up. Note that delivered methanol usually costs more per gallon of gasoline equivalent (gge) than delivered gasoline from methanol because the delivery charge per gge is twice as high for methanol as for gasoline, due to the lower energy content of the former.
[b] 10-percent real return on investment.
[c] 10-percent real return on equity investment, 5-percent real investment on debt.
[d] Involves coproduction of synthetic natural gas.
[e] Numbers in parentheses assume methanol used in engine designed for methanol use which is 20 percent more efficient than a corresponding gasoline engine.
[f] Methanol is principal product.
[g] Gasoline is principal product.

SOURCE: Office of Technology Assessment.

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sumer costs change with the required rate of return on investment.

As mentioned above, plant performance is an important determinant of the cost of synfuels from the first generation of plants. Because the selling price of the synfuels probably will be determined by the competing price of petroleum fuels, poor plant performance may translate into a low return on investment or a financial loss. In recognition of this possibility and the large number of very profitable investments currently available to the energy industry, most investors are likely to require a high potential rate of return on investment before proceeding with a synfuels project.

In other words, in the absence of loan guarantees to enable high debt financing, conventional liquid fuel prices could easily have to exceed $2.00/gal of gasoline equivalent (1980 dollars) before synfuels would be widely perceived as a good risk.* Once the technologies are commercially proven, however, fuel prices shown in table 16 could provide adequate incentives for investment, provided that the solution of any technical problems uncovered in the first commercial plants does not significantly increase the required plant investment.

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*Some companies in a good capital position might be willing to take the higher risk to gain experience and/or an early market share, however.

Box C.—Total Cost and Investment Cost

In comparing the costs of the various options for reducing conventional oil consumption, we have, for three reasons, emphasized investment costs, rather than total costs (or consumer costs) per unit of oil saved or replaced. First, consumer costs are considerably less certain than investment costs because of site-specific factors and technical and financial uncertainties. Second, because different consumers will discount future fuel savings at quite different rates, the total costs seen by consumers will be highly variable (even for the same option). Furthermore, the costs of the various options require different proportions of investment costs (which may be discounted) to changes in operating costs (which are not discounted). Finally, each of the options for reducing oil consumption is capital-intensive and it will require hundreds of billions of dollars in investments to reduce oil imports significantly; these investments will come at the expense of other investments in the economy and direct consumption. From a national perspective, it is important to compare the options with respect to the investment needed per unit reduction in oil use to see if any of the options is significantly less capital-intensive than the others.

Total cost to consumers (per unit oil saved or replaced) does, however, have a strong influence on the extent to which each option actually is implemented. Although specific values for the total cost to consumers are not given here, some of the uncertainties in, and factors influencing, total cost are discussed below. It should be emphasized, however, that the costs of some of the options may not equal the price. Price will be determined by market forces.

Increased Automobile Fuel Efficiency

Fuel efficiency cannot be neatly separated from other attributes of a car, and there is always a certain ambiguity in determining what fraction of production costs should be ascribed to fuel efficiency. In addition, depending on the demand for fuel efficiency, varying fractions of the investments associated with increasing fuel efficiency could be ascribed to and incorporated in "normal" capital turnover in the auto industry.

Beyond these accounting difficulties, there are uncertainties in the investments needed to make various changes in automobile production facilities and in the size of the resultant fuel-efficiency increases. And another important factor affecting total cost is any change in variable costs (materials and labor) associated with producing more fuel-efficient cars. Whether or not variable costs increase will depend on the success of adapting and developing low-cost processes for manufacturing the more fuel-efficient cars, and the outcome of the development efforts cannot be readily predicted.

A final area of uncertainty involves the rate that consumers discount (i.e., how much they value) future fuel savings. For example, discounting future fuel savings at 25 percent per year in-

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creases the apparent cost of fuel efficiency per gallon saved by a factor of 2.5 over the situation where no discount is applied to future fuel savings. In practice, there will be a wide variety of discounting rates used by various consumers, and the rates will change with market conditions (including oil prices and interest rates) and consumers' beliefs about future oil prices and availability, among other things.

Synthetic Fuels

For synfuels processes that produce sizable quantities of different fuel products (e.g., synthetic natural gas and fuel oil), one encounters accounting problems similar to those discussed under increased automobile fuel efficiency—i.e., how to allocate production costs to the various synfuels products. However, these problems are less severe for synfuels than for automobiles because all of the major products of the former are separate consumer products with known current prices. Furthermore, the accounting problems can be largely avoided by considering only processes that produce only fuels of similar quality (e.g., gasoline, jet, and diesel fuel), and avoided entirely by considering processes that produce only one major product.

Variations in operating and maintenance costs and future coal prices produce some uncertainty in the cost of synfuels. The more important uncertainties, however, involve the cost of building a synfuels plant, how this cost will be financed, and investors' required rates of return on investment. The cost of synfuels from the first generation of synfuels plants will also depend critically on plant performance, with frequent shutdowns and repairs increasing costs dramatically. Presumably, later generations of plants will perform reliably.

Fuel Switching and Conservation

The total cost of switching utility boilers from fuel oil to coal is fairly well known. There are, however, some areas of the country where coal is not readily available, and there is insufficient space to accommodate coal handling facilities at some electric generating plants.

The major variability in the cost of switching to natural gas and electricity for buildings and in industry results from widely varying required rates of return on investments in different industries and for different building owners or renters. At some sites, though, natural gas is not available or space limitations prevent the installation of gas facilities. There is also uncertainty in the cost of finding and processing unconventional natural gas (from tight sands, etc.).

The total cost of conserving heat and hot water in buildings is probably the least certain of the measures for reducing stationary oil use. Not only are there large uncertainties and variability in the savings that can be achieved through various conservation measures, but also consumers will discount future fuel savings at widely differing rates.

HOW DO THE ENVIRONMENTAL IMPACTS OF INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNFUELS COMPARE?

The synfuels, auto fuel efficiency, and electric auto alternatives for displacing imported oil have sharply different potential impacts on public health and safety, on workers, and on ecosystems. In addition, probabilities of these impacts actually occurring—few of them are inevitable—are also quite different. Both the potential impacts and their risks are briefly compared below. The nature of some of the risks, however, is obscured by the brevity of the following discussion. For example, the actual risk associated with possible contamination of drinking water by synfuels production is heavily dependent on the degree of prior recognition of the risk and response to this recognition—for example, development of ground water monitoring systems. Also, risks that are similar in magnitude are often valued differently because of the degree of choice involved (e.g., willing exposure to the risks of auto travel v. unwilling exposure to accidental toxic spills) and the precise nature of the risks (e.g., multiple automobile accidents involving only a few peo-

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ple at a time v. a serious accident or control failure at a large synfuels plant).

Public Health and Safety

Reductions in vehicle size, part of the auto fuel-efficiency measures, could have the strongest effect on public health and safety through their potential adverse effects on vehicle safety. The effect is difficult to estimate because of a lack of comprehensive traffic safety data that would allow an evaluation of the relative effect of car size and other key safety variables on vehicle crashworthiness and accident avoidance, and because of uncertainty about the compensatory measures that might be taken by the vehicle manufacturers and by drivers. Although the National Highway Traffic Safety Administration has projected vehicle size reductions to cause an additional 10,000 annual traffic deaths by 1990 if compensatory measures are not taken, this and other quantitative estimates of changes in traffic safety are based on limited data and relatively crude models. Nevertheless, an increase in traffic deaths of a few thousand per year because of vehicle size reductions does seem plausible.

Diesel use could have an adverse effect on emissions of nitrogen oxides (NO_x) and particulates, and conceivably could cause public health problems in congested urban areas. The risk is moderated, however, because: 1) controls for NO_x and particulates are under active development, although success is not assured and it is possible that the current level of effort will not be continued; and 2) the evidence for health damage from diesel particulates is equivocal.

Electric passenger vehicles are likely to be small, and thus should share safety problems with radically downsized high-mileage conventional automobiles. Additional safety problems caused by the batteries, which contain toxic chemicals that may be hazardous in an accident-caused spill, are offset somewhat by eliminating the fuel tank with its highly flammable contents. Also, electric cars should have a positive effect on air quality, especially in urban areas, because the reductions in automobile emissions outweigh increased emissions from powerplants, except for sulfur dioxide (SO_2).

Synfuels plants may expose the general public to health and safety hazards in a variety of ways: contamination of drinking water from leaching of wastes, accidental spills, or failure of effluent controls; accidental release of toxic vapors; exposure to contaminated fuels; and routine emissions of conventional air pollutants such as SO_2 and NO_x. Only the routine emissions are essentially inevitable, however, and health and safety problems from these should be minimized by Federal ambient air quality standards and by the relative magnitude of these emissions, which should be considerably lower than emissions from projected levels of development of coal-fired electric generation during the same time frame. The extent of risk from the other sources is not well understood because the toxic waste streams from the plants have not been fully characterized, the effects of some of the known and suspected waste products are not yet well understood, and the effectiveness and reliability of some critical environmental control systems have not been demonstrated under synfuels plant conditions (see issue on p. 95). Chemical industry sources believe that few problems will arise, but, as discussed in the above-mentioned issue, some areas of concern remain.

Worker Effects

With the possible exception of some worker exposure to toxic materials in battery manufacture, the only significant occupational health and safety problem associated with the automobile measures appears to be mine safety and health effects involved in any increased mining of coal for electricity needed for recharging electric car batteries, and, to a lesser extent, for aluminum manufacture. These impacts are not trivial, because the amount of coal needed *per barrel of oil saved* for electric cars is of the same order of magnitude as that needed for synfuels production (assuming coal-fired electricity and coal-based synfuels). The coal-to-oil balance for aluminum use is somewhat less certain, although some analyses have calculated it to be similarly high. The use of aluminum is not the major part of the efficiency measures, however, and the actual amount of coal required is not likely to be significant in comparison with the coal used for synthetic fuels.

As noted, synfuels production has a coal requirement similar to that of electric autos, and thus shares similar mineworker problems. It has important additional problems. The sources of moderate risks to public health and safety—fugitive emissions, spills, plant accidents, and contaminated fuels—pose more serious risks to workers because of their frequency and severity of exposure. For example, workers will be continuously exposed to low levels of polynuclear aromatics and other toxic substances because fugitive emissions cannot be reduced to zero. Another important source of possible worker exposure is the maintenance requirements of synfuels reactors; the materials that must be handled in these operations are likely to have the highest concentrations of dangerous organics.

Exposure to hazardous substances is common in the petrochemical industry, and worker-protection strategies developed in this and related industries will be used extensively in synfuels plants. These strategies clearly will reduce the hazards, but the degree of reduction is highly uncertain (see issue on p. 95).

Ecosystem Effects

The only significant sources of ecosystem effects from the automobile measures are likely to be the changes in air quality caused by the use of electric autos (which probably will be positive) and diesels, and the air, land, and water pollution associated with the mining and processing of both coal for electricity (for battery recharging or aluminum production) and battery materials such as lead and lithium. Obtaining the new battery materials is thought unlikely to cause important environmental problems, but there are many different kinds of potential battery materials, and final judgment probably should be withheld at this time. Nevertheless, with the exception of the electric-car coal-mining requirements, any adverse ecosystem effects of the automobile measures appear likely to be mild.

Synfuels production is likely to cause significantly greater adverse effects, because it will have coal-mining damages per barrel of oil roughly similar to electrical autos *as well as* several additional and potentially important adverse impacts. These include substantially increased mining and waste disposal requirements if oil shale is the synfuels feedstock, and a variety of potential adverse impacts stemming from the possibility that toxic materials generated during the conversion processes will escape to the environment. The pathways of potential damage from toxics are essentially identical to those threatening public health and safety—surface and ground water contamination, toxic vapors, and exposure (in this case from spills) to contaminated fuels. Unfortunately, probability of the damage actually occurring is equally difficult to evaluate.

An additional concern is that synthetic fuels from biomass sources—which in general have similar or less severe environmental problems than coal-based synfuels—may have more severe ecosystem effects because of the very extensive nature of their resource base. The adverse ecosystem effects of large increases in grain production to produce gasohol, for example, can be quite serious, and, given the nature of the current agricultural system, the probability of such effects occurring is high.

Summary

The environmental impacts of increased automobile fuel efficiency and synthetic fuels development will be quite different and difficult to compare. The major impacts of auto efficiency improvements are likely to be increases in crash-related injuries and fatalities from auto size reductions. The severity of these impacts is heavily dependent on vehicle design and driver behavior (especially seatbelt usage). Synthetic fuels development's major impacts will include the well-known ecosystem effects as well as public and worker health and safety effects of large-scale mining and combustion of coal. Oil shale development will have many similar effects; a most serious environmental risk may come from inadequate disposition of the spent shale. In addition, there are *potentially* serious impacts on people and ecosystems from the escape of toxic substances from synfuels conversion processes. The severity of these impacts is unclear because important waste streams have not been characterized and environmental control effectiveness and reliability has not been demonstrated.

HOW WILL THE SOCIAL IMPACTS OF SYNFUELS AND INCREASED AUTOMOBILE FUEL EFFICIENCY COMPARE?

Identifying, assessing, and comparing the social impacts of synfuels development and improved automobile fuel efficiency are difficult because these impacts will not be distributed evenly in time or among regions. Moreover, they cannot necessarily be measured in equivalent (e.g., dollar) terms, and they are difficult to isolate and attribute to specific technical choices. Both beneficial and adverse social consequences will arise from these two approaches to reducing oil imports.

Employment

Synthetic fuels production presents two major considerations about social impacts related to employment. First, there is the possibility of shortages of experienced chemical engineers and skilled craftsmen. A rapid growth in synfuels would likely put increased pressure on engineering schools, which are now suffering from insufficient numbers of faculty. The second concern arises from the large and rapid fluctuations in labor requirements for construction. While no shortages of construction workers are expected, on the average, fluctuating labor requirements during construction and startup can have severe secondary effects on communities at the construction sites. A population increase of about three to five people per new worker could occur, leading to possible population fluctuations of 30,000 to 60,000 people for some synfuels construction.

The changing structure and markets of the established automobile industry are likely to lead to a long-term, permanent decline in auto-related industrial employment. The nature of this decline will depend on import sales, the growth rate of the U.S. auto market, the competitiveness and labor intensity of U.S. manufacturing, the use of foreign suppliers and production facilities, and the adoption of more capital-intensive production processes and more efficient management practices. The skill mix will also shift increasingly towards skilled labor. Scarcities of experienced engineers and certain supplier skills could inflate the prices of skilled manpower resources for both synfuels and changing automotive technology.

Community Impacts

Synfuels development will have its most immediate effect in relatively few small and rural oil shale communities in the West, as well as in the small rural communities located near many of the Nation's dispersed coal resources. In the long term, local communities should benefit from synfuels in terms of expanded tax bases and increased wages and profits. However, in the near term, there are risks of serious disruptions in both the public and private sectors of these communities. The nature and extent of these disruptions will be determined by the community's ability to absorb and manage growth, and the rate and scale of local synfuels development.

Automobile production jobs are presently concentrated in the North-Central region of the Nation. The geographical distribution can be expected to change as inefficient plants are closed and new production facilities are established in other parts of the United States. New plants will provide new employment opportunities with accompanying community benefits (e.g., tax revenues); plant closings in areas heavily oriented towards the auto industry would deepen the existing economic problems of the North-Central region, i.e., high unemployment, rising social welfare costs, and declining tax base.

HOW DO THE REGIONAL AND NATIONAL ECONOMIC IMPACTS OF SYNFUELS AND INCREASED AUTO EFFICIENCY COMPARE?

In addition to comparisons on the basis of cost per barrel, environmental impacts and local social impacts, increased automobile fuel efficiency and synfuels can be compared on the basis of their potential regional and national economic impacts. The latter comparison is important because each type of investment implies an alternative national strategy to achieve the goals of price stability, national economic growth, and equity as well as oil import reduction.

Regional and national aggregation are also important because both industries are capital-intensive. Large blocks of investment must be mobilized, with key investment decisions made by a relatively small number of firms, based on very uncertain longrun predictions about the future. As summarized below, a variety of important national and regional issues are raised by the uncertainties and inflexibilities inherent in these decisions.

Inflation and Economic Stability

Inflation may be dampened and the economy stabilized if either type of investment is successful. In the case of synfuels, if first generation plants demonstrate competitive costs, the mere prospect of rapid deployment could moderate oil import prices and thus help to control what has been one of the major inflationary forces during the last decade. In the case of autos, if increased fuel efficiency helps domestic firms to hold or perhaps increase their market share, this would keep U.S. workers employed and at least stabilize foreign payments for autos. Higher employment also tends to reduce Federal transfer payments, which either reduces the Federal deficit or lowers taxes. Reductions or stabilization of foreign payments tends to strengthen the value of the dollar in foreign exchange markets. Both changes, in the Federal budget and on foreign accounts, reduce inflationary pressure.

On the other hand, attempts to displace oil imports too quickly may be inflationary. Risks of inflation, technical errors, and market miscalculations all increase with the rate of synfuels deployment and with shortening the time taken to convert the domestic auto fleet to high fuel efficiency.

In the case of synfuels, rapid investment growth in the next decade, beyond construction of demonstration projects, could cause inflation by creating suppliers' markets in which prices for construction inputs, especially chemical engineering services, can rise more rapidly than the general inflation rate. Deployment prior to definitive testing in demonstration plants also compounds potential losses due to design errors.

In the case of autos, rapid large-scale investments can inflate prices of vehicles as firms attempt to amortize capital costs quickly. However, if these attempts fail, presumably because buyers stop buying high-priced domestic autos, then newly invested capital must be written off prematurely, resulting in the waste of scarce resources for the firm and the Nation. Furthermore, if rapid fuel-efficiency improvements are forced by abrupt, real fuel price increases or by aggressive foreign auto competition, then the domestic auto industry and owners of fuel-inefficient cars will both be forced to absorb lump sum losses in the real value of current assets. Low prices for new cars resulting from competition do, however, benefit purchasers of these cars.

Employment and International Competition

If improved fuel economy makes domestically produced autos more competitive with imports, there will be two major national economic payoffs besides fuel savings. First, this improved competitiveness will protect traditional U.S. jobs; second, it will reduce the drain of foreign payments to auto exporting countries as well as to oil exporters. Synfuels do *not* present a similar coupling of economic possibilities.

There are major doubts, though, about the longrun success of U.S. automakers with foreign competition. The United States may not be able to compete in the mass production of fuel-efficient autos for a variety of reasons—such as high wages, low productivity, and inefficient or out-of-date management. All such explanations are speculative, but together they have raised serious doubts about U.S. competitiveness in the context of the recent, rapid increase in the market share of auto imports. If foreign automakers continue to drive domestics out of the market for fuel-efficient autos, synfuels investments may be preferred over investments in fuel efficiency even if the apparent cost per barrel of the former are higher.

Assuming investment in either industry does lead to increased U.S. production, employment opportunities for synfuels and autos can be compared based on 1976 data (the most recent available). Synfuels production involves mainly mining and chemical processing activities, which in 1976 dollars had $59,000 and $55,000 invested per worker respectively. On the other hand, the transportation equipment sector of the economy (which is dominated by autos) had $27,000 invested per worker and auto suppliers such as fabricators of metal, rubber, and plastic products had about $21,000 per worker. In other words, in the recent past the auto industry created about twice as many jobs per dollar of investment as industrial activities similar to synfuels. The current trend toward automation in automaking will undoubtedly lower its labor intensity, but the auto industry should continue to employ more workers per unit of investment.

Income Distribution Among Regions

Another question concerns the likely regional distribution of incomes from autos and synfuels. An analysis of location factors was not carried out, but two points can be made. First, to the extent that the auto industry could use existing plants or build nearby, current employment patterns and established communities could be maintained. This would preclude costly relocation and would tend to favor the North-Central region of the United States, which has been losing its industrial base.

Second, new auto plants can be located in more areas of the country than new synfuels plants because of the high cost of transporting synfuels feedstocks, especially oil shale, compared with the cost of transporting manufactured materials and parts for automobiles. Transportation costs are likely to concentrate synfuels investments in regions of the Nation with superior shale and coal reserves. Biomass options are least likely to be concentrated, because resources are dispersed, and coal-based options are much more flexible than shale because coal is more widely dispersed.

Capital Intensity and Ownership Concentration

Finally, both strategies for oil import substitution affect the number of profitable firms in each industry. In both industries, the number of competitive firms is severely constrained by the size of investment outlays and by the acquired knowledge of those already in the business.

In liquid fuels, the introduction of synthetic fuels sharply increases the amount of capital investment required per barrel of liquid fuels production capacity. For example, in the case of one major oil company, present capitalized assets per average daily barrel of oil equivalent of production from old reserves of conventional oil and natural gas is less than 20 percent of OTA's estimate of the similar ratio for oil shale.* However, new reserves of conventional oil and gas will also require much larger capital outlays than old reserves, due to depletion of finite natural resources.

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*Value of assets for Exxon was obtained from its 1980 Annual Report.

From the investor's viewpoint, the sequence of investments for conventional petroleum resources is very different from synfuels projects. For conventional petroleum, small operators can explore for new reserves, at least on shore, with only a relatively small amount of high-risk money and the limited technical staff required to rent a drilling rig and to determine where the wildcat well should be drilled. If a discovery is made, subsequent, much larger investments in development wells and pipelines can be made at relatively low risk. In synfuels, a firm simply cannot enter the business without command of all capital requirements up-front, or without a very large staff of technicians and managers.

In summary, investment options to discover and develop conventional oil and gas will be exploited before synthetics even if estimated total capital outlays are the same, because the former confine major risks to the front-end of projects before the largest blocks of capital must be committed.

As a result, it is likely that only a very small fraction of the hundreds of firms currently producing conventional oil and gas will have the financial and technical means to produce synfuels when conventional resources are depleted. While this growing concentration of ownership may not lead to the classical problem of price fixing by domestic producers, because oil and gas are traded on worldwide commodity markets, it does at least make the industry appear to be more monolithic, since synfuels project managers will command very large blocks of human and material resources.

In domestic automaking, ownership may become more concentrated because at least two out of the three major U.S. companies are being forced, by lack of capital and perhaps by high production costs, to curtail the number of different vehicles made. Although foreign automakers are increasing their U.S. manufacturing activities, the growing dominance of one major U.S. automaker over the other two may decrease price competition in certain types of cars and possibly reduce profitmaking opportunities for domestic suppliers to auto manufacturing because of the market leverage of the one dominant buyer.

WHAT DO INCENTIVES FOR INCREASED FUEL ECONOMY IMPLY FOR THE EVOLUTION AND HEALTH OF THE U.S. AUTO INDUSTRY?

The auto industry began a process of structural changes in the 1970's which complicates evaluation of how fuel economy policy might affect the industry, auto manufacturing communities, and the national economy. Regardless of fuel economy policy, the U.S. auto industry is undergoing a long-term decline in terms of employment, the number of domestic firms (including suppliers), and the proportion of global auto production sited in the United States. Recent consumer demand for fuel economy and other auto characteristics have supported these trends by motivating costly product changes to meet competition from foreign firms. Factors such as the relatively fast sales growth in foreign auto markets and lower costs of labor and capital abroad have induced U.S. manufacturers to increase investments in foreign production activities.

Increases in demand and other pressure on U.S. firms to raise fuel economy will reinforce and perhaps accelerate current industry and market trends. Although large spending needs will motivate reductions in the number of independent firms and, perhaps, the breadth of their operations, the size and financial health of the U.S. auto industry in the future will depend, to a great degree, on its ability to compete with foreign firms—particularly in the small-car market. The competitiveness of U.S. auto firms depends not only on product designs and production facilities but also on total manufacturing costs, which reflect labor costs and the efficiency of production, organization, and management. Incentives for accelerating fuel-efficiency increases will not only directly affect the investment requirements, but a combination of high perceived investment needs, possible rigidity in U.S. costs, and a slow-growing competitive U.S. market may discourage U.S. firms from investing in U.S. capacity.

There are some auto company activities that should be relatively invulnerable to fuel economy-motivated market changes and should continue in the United States. These activities include production of specialty cars and nonautomotive projects such as defense contracting. U.S. auto companies may continue to conduct some activities in the United States at historic or greater levels, while they may reduce the levels of others or eliminate them entirely.

A decline in U.S. auto production, especially one that is not substantially offset by growth in foreign-owned capacity in the United States, poses a major policy dilemma. On the one hand, the auto industry metamorphosis may result in a more economically efficient domestic industry that is more competitive with strong import competition. On the other hand, the process of industry change results in loss of jobs for current autoworkers and loss of employment and business activity for local economies, losses which are relatively large and regionally concentrated in the already economically depressed North-Central region. These concerns can be dealt with through industrial and economic development policies, but it should be recognized that policy to accelerate fuel economy improvements may aggravate them. In addition, many of these changes may occur even in the absence of strong demand for fuel efficiency, but possibly at a slower rate.

CAN WE HAVE A 75-MPG CAR?

There are no *technological* barriers to designing and building a four-passenger automobile that could achieve 75 mpg on the combined 55/45 percent highway/city EPA driving cycle. Such a car would take at least 5 years to design and develop and might be costly to manufacture, but it is technically feasible. It should be noted, of course, that the appearance of one or a few models that get 75 mpg would have little immediate effect on *fleet* average fuel economy, or on the Nation's petroleum consumption.

High fuel economy entails tradeoffs and compromises that affect other features of vehicle design—carrying capacity, performance, safety, comfort, and related amenities. Technology *is* a critical factor in managing these tradeoffs. Some routes to improved passenger car fuel economy also increase manufacturing costs (diesel engines, more complicated transmissions, lightweight materials). Here again, better technology can help to improve fuel economy at the least cost.

If a 75-mpg car can be made sufficiently attractive to consumers in terms of the other features beyond fuel economy that affect purchasing decisions—including price, but also the variety of less tangible factors that contribute to perceived value—then automakers will build such cars, confident that they will find a market. The interplay between consumer demand and automotive technology will determine *when* 75-mpg cars will appear. Consumer expectations concerning fuel costs and the possibility of future shortages of fuel, as well as their judgments of the practicality of such cars, will be important factors affecting the rate at which these cars would be introduced.

An automobile designed to achieve 75 mpg might *look* much like a current subcompact—e.g., a General Motors Chevette—but, as discussed in chapter 5, would be considerably different under the skin. It would have to be lighter, and might also be somewhat smaller—with a curb weight of perhaps 1,600 lb as opposed to about 2,000 lb for the Chevette. The actual weight depends not only on the size of the car, but also on the materials from which it is made. By using materials with high strength-to-weight ratios wherever possible—or, where strength or stiffness are not important, materials of low density—a four-passenger car could weigh, in principle, even less than the 1,600 lb suggested above. Costs are the limiting factors in the use of such materials—both the costs of the materials themselves and the costs of the required manufacturing processes.

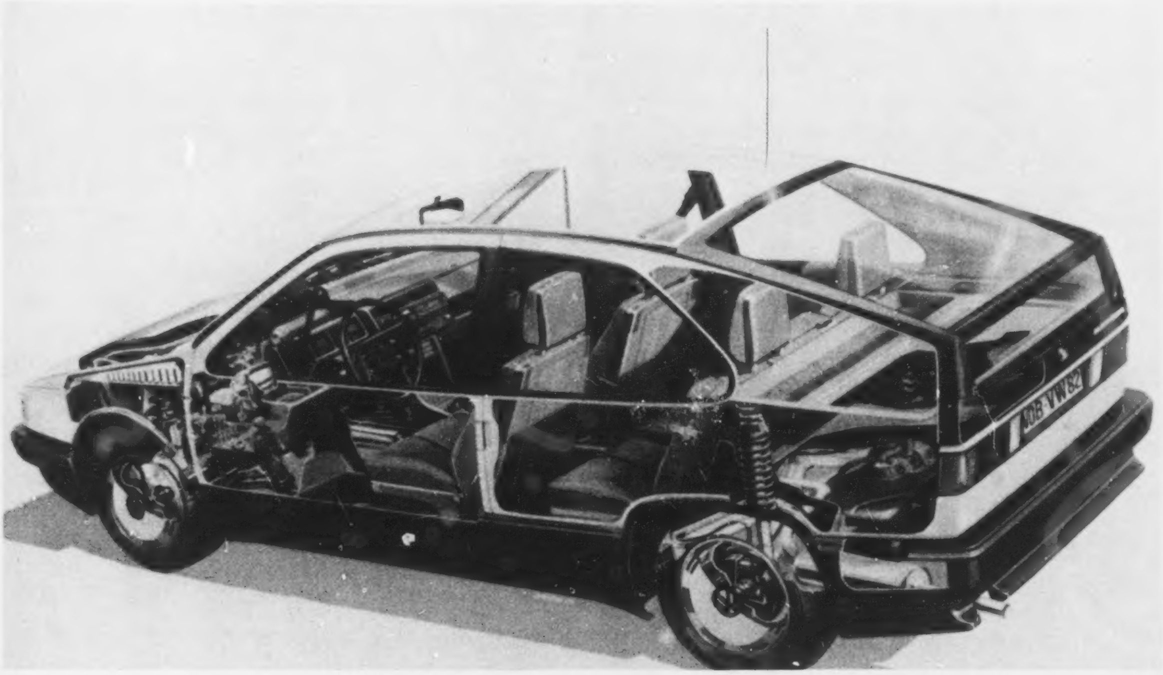

Photo credit: Volkswagen of America

Artists drawing of the VW2000, a three-cylinder diesel test vehicle that has achieved over 60 mpg in standard fuel-efficiency tests

The other essential element in a 75-mpg car is an efficient powertrain. For a car weighing 1,600 lb or less, a relatively small diesel engine—one with a displacement in the range of 0.9 to 1.3 liters—would suffice. The transmission could be either a manual design or a considerably improved automatic, perhaps a continuously variable transmission.

To get 75 mpg would also require a great deal of attention to the detailed design of many aspects of the car—low aerodynamic drag, low rolling resistance, use of microprocessor controls, minimal accessories, and parasitic loads—with careful engineering development throughout the vehicle system. None of this depends on technological breakthroughs.

Given equally good design practices, the resulting car would not be as safe as a larger vehicle. Nor would it be luxurious. It might not have air conditioning. It would probably not be able to pull a camping trailer through the Rocky Mountains. But it could get 75 mpg. When automobile manufacturers—here, in Europe, and in Japan—decide that American consumers want such a car, they will build it.

ARE SMALL CARS LESS SAFE THAN LARGE CARS?

One of the easiest ways to increase the fuel economy of passenger cars is to make them lighter. Although it is possible to make cars somewhat lighter without making them smaller, in general size and weight go together. Thus, cars with increased fuel economy are typically smaller—a downward trend in the size and weight of cars sold in the U.S. market began in 1977 and will continue through the 1980's, although gradually leveling off.

Size is the more critical variable for safety, although weight also affects the dynamics of collisions. *A great deal of improvement in the safety of cars of all sizes is possible through improved design—but given best practice design, a big car will always be safer than a small car in a collision.* As a result, making cars smaller to improve fuel economy will, everything else being equal, increase risks to drivers and passengers. Assuming no change in the way the cars are driven, there will be more injuries and fatalities than would occur with bigger cars embodying equivalent design practices and having identical accident avoidance capabilities.

Size affects safety because when an automobile hits another object—whether another car, a truck, or a roadside obstacle—the car itself slows, or is decelerated (the "first collision"), and the occupants must then be slowed with respect to the vehicle (the "second collision"). To minimize the chance of injury, the decelerations of the occupants with respect to the passenger compartment during the second collision must be minimized. The occupants must also be protected against intrusion or penetration of the passenger compartment from the outside. But controlling decelerations during the second collision depends on the deceleration of the entire vehicle during the first collision. Given good design practices, the severity of both the first and the second collision can be lowered, on the average, if the car is made larger.

Ideally, the vehicle structure will deform in a controlled manner around the passenger compartment during a collision, so that the average deceleration of the passenger compartment in the first collision will be low. The larger the car, the more space the designer can utilize to manage the deformations and decelerations—e.g., by using a crushable front-end. In a small car, there is less room for controlled deformation without intruding on the passenger compartment. Within the passenger compartment, more space means more room to control the deceleration of the passengers—using belts, harnesses, padding, and other measures—with less risk of hitting unyielding portions of the vehicle structure. More room also makes penetration or other breaches of the integrity of the compartment less likely. One pathway to increased fuel economy without sacrificing collision protection is therefore to make cars lighter by design changes and/or different materials while preserving as much space as possible for managing the energies that must be dissipated in the first and second collisions.

Because vehicle size and weight are not the only significant factors in determining vehicle safety, and because "all other things being equal" does not apply in actual real-world situations, any conclusion about the relative safety of large and small cars should be tempered with the following observations:

1. The recent series of crash tests sponsored by the National Highway Traffic Safety Administration demonstrated that vehicles of approximately equal size can offer remarkably different degrees of crash protection to their occupants. In many cases, differences between cars of equal size overshadowed differences between size classes in the kind of accident tested (35-mph collision head-on into a barrier).
2. Crash-avoidance capabilities of large and small cars are unlikely to be the same, and any differences must be factored into an evaluation of relative safety. Unfortunately, the effects of differences in such capabilities are difficult to measure because they represent both physical differences in the vehicles and driver responses to those differences.
3. Available traffic safety data and analysis is often confusing and ambiguous on the subject of large car/small car safety differences.

Although analyses of car-to-car crashes tend to agree that occupants of large cars are at a lesser risk than those of smaller cars, there is no such firm agreement about the other classes of accidents that account for three-quarters of all passenger vehicle occupant fatalities. A probable reason for the ambiguity of results is the shortage of consistent, nationwide data on accident incidence and details; only fatal accidents are widely recorded. Another reason is the multitude of factors other than car size that might affect injury and fatality rates. Important factors include differences (among different size classes) in driver and occupant age distribution, general types of trips taken, average annual mileage, vehicle age distribution, and seatbelt usage.

HOW STRONG IS CURRENT DEMAND FOR FUEL EFFICIENCY IN CARS?

An extremely important factor influencing future new-car average fuel efficiency is the market demand for this attribute, relative to the other features the new-car buyer wants. Although it is, at best, only an approximate measure of future market behavior, examination of recent demand patterns in the new-car market can provide some insights about current demand for fuel efficiency. In particular, the importance of fuel efficiency as compared with car size, price, and performance is examined for 1981 model gasoline-fueled cars* sold through January 5, 1981.

Table 17 presents a comparison of the average fuel efficiency of new gasoline-fueled 1981 model cars sold through January 5, 1981, with the fuel efficiency of the most efficient car in each of the Environmental Protection Agency's (EPA) nine size classes. Also shown are the sales fractions and the nationality of the manufacturer of the most efficient vehicle. These data show that the average fuel efficiency of new cars sold was 25 mpg, but if consumers had bought only the most fuel-efficient car in each size class* (and manufacturers had been able to supply this demand),

Table 17.—Comparison of Average and Highest Fuel Efficiency for 1981 Model Gasoline-Fueled Cars in Each Size Class

EPA size class	Sales fraction (percent)	Sales-weighted average fuel efficiency of cars sold through Jan. 5, 1981 (mpg)	Fuel efficiency of most fuel-efficient model in size class (mpg)	Nationality of manufacturer of most fuel-efficient model
Two-seater	2	22	30	Italian
Minicompact	3	34	45	Japanese
Subcompact	30	28	42	United States (Captive Import)
Compact	9	27	37	United States
Midsize	37	23	31	United States
Large	9	20	24	United States
Small wagon	4	30	37	Japanese
Midsize wagon	5	23	30	United States
Large wagon	1	18	20	United States
Sales-weighted average		25	33	

SOURCE: Data from J. A. Foster, J. D. Murrell, and S. L. Loos, U.S. Environmental Protection Agency, "Light Duty Automotive Fuel Economy . . . Trends Through 1981," SAE paper No. 810386, February 1981.

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*The results of the analysis would change somewhat if diesels were included, primarily with respect to nationality of manufacturers because U.S. manufacturers did not offer diesels in several size classes in 1981. U.S. manufacturers, however, are beginning to offer diesels in most size categories; but the relevant data are not now available. In 1981, about 95 percent of the automobiles sold were gasoline-powered.

*Interestingly, this would also have resulted in U.S. manufacturers and captive imports capturing over 90 percent of sales, rather than 74 percent of sales that they actually achieved in this period. If diesels are included, however, average fuel efficiency could have been slightly higher than 33 mpg, but less than 60 percent of the cars purchased would be domestically produced.

the average fuel efficiency would have been 33 mpg (a 33 percent increase). Because EPA's size classes are based on cars' interior volume, it is clear that demand for large interior volume in cars is not currently preventing a significantly higher average fuel efficiency in new cars than is actually being purchased.

Similarly, a comparison of prices shows that the most fuel-efficient 1981 model cars generally had a base sticker price in the middle or lower half of the price range of cars in each size classification.* Thus, there is no evidence that price is constraining the purchase of fuel-efficient cars either.

A further comparison of the average and most fuel-efficient cars in each size category shows that the average cars are heavier and have more powerful engines than the most fuel-efficient models. However, OTA's analysis indicates that the greater engine power found in the average car sold is, to a large extent, needed simply because the car is heavier.** There is no indication that the most fuel-efficient car in most size categories performs (e.g., accelerates) significantly worse than the averge 1981 model car actually sold in that category. Although there are exceptions to this in certain size categories (e.g., two-seaters, large cars, and possibly midsized station wagons), these exceptions account for only about 10 to 15 percent of total sales.

This analysis indicates that interior volume, price, and performance cannot account for the large difference between the fuel efficiency of cars actually sold and what was available. As in the past, consumers consider features such as style, quality, safety, ability to carry or haul heavier loads, and energy-intensive accessories to be of comparable importance to fuel economy. It is probable, therefore, that new-car average fuel efficiency could be significantly increased if consumer demand for fuel economy were strengthened.

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*Sales-weighted average sticker prices for comparably equipped cars are not currently available.

**For example, in subcompacts and midsized cars (accounting together for 67 percent of sales), the average car weighed about 33 percent more and had about 50 percent larger engine displacement (which is correlated to power) than the most fuel-efficient car. A further comparison of specific fuel efficiency (ton miles per gallon, or the mpg of an equivalent car weighing 1 ton) shows that, for midsized cars (37 percent of sales), the difference in fuel efficiency between the average and the most fuel-efficient car can be explained solely on the basis of weight. Thus, there is no indication that the average car has better performance characteristics (e.g., acceleration) than does the most fuel-efficient model. A similar comparison of subcompacts indicates that, if anything, one would expect the most fuel-efficient model to perform better than the average.

WHAT ARE THE PROSPECTS FOR ELECTRIC VEHICLES?

EVs were among the first cars built, but they had almost vanished from the marketplace by the 1920's, primarily because they could not compete with gasoline-powered vehicles in terms of price and performance. Due to concern over automobile emissions, the increasing price of oil and recent oil supply disruptions, however, there has been a renewed interest in this technology. The advantages of EVs are that they derive their energy from reliable supplies of electricity, which can be produced from abundant domestic energy sources, and they operate without exhaust emissions. Their disadvantages are their high cost and poor performance and the increased sulfur dioxide emissions that result from increased electric generation.

From the consumer's point of view, the problems with EVs are principally centered on battery technology. Current batteries are expensive and heavy, relative to the energy they store; they require several hours to recharge; and they must be replaced approximately every 10,000 miles at a cost of $1,500 to $3,000. The weight of batteries limits vehicle range,* performance, and cargo- and passenger-carrying capacity. Because of the cost of batteries and electric controls, a new EV is estimated to cost about $3,000 more than a comparable gasoline-powered vehicle. And replacing batteries every 10,000 miles because of limited life would add more than $0.10/mile to operating costs, which is equivalent to gasoline costing more than $4 to $6/gal for a 40- to 60-mpg car.

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*Usually 100 miles or less between rechargings.

Future developments in battery technology could improve the prospects for EVs, and several approaches are being pursued. But the understanding of battery technology is not adequate to predict if or when significant improvements will occur.

If battery problems persist, sales of EVs could be limited to a relatively few people and firms that can afford to pay a premium to avoid transportation problems that would arise if liquid fuel supplies were disrupted. On the other hand, if gasoline prices increase by more than a factor of four or five or if gasoline and diesel fuel are rationed at levels too low to satisfy driving needs even with the most fuel-efficient cars, then EVs could be favored—provided electricity prices do not also increase dramatically.

Prospects for EVs may also be influenced by Government incentives based on national and regional considerations. One such consideration is the oil displacement potential of EVs. EVs are most nearly a substitute for small cars, which are likely to be relatively fuel efficient in the 1990's; but the limited range of current and near-term EVs prevents them from being a substitute for all of the yearly travel needs supplied by a small gasoline-driven car. As a result, oil displacement by EVs is likely to be relatively small; probably no more than 0.1 million barrels per day (MMB/D) with a 10-percent market penetration, even assuming no oil consumption by those electric utilities supplying electricity to EVs.

At current levels of utility oil consumption, however, the net oil displacement would be less than 0.1 MMB/D (see ch. 5 for details). Future reductions in utility oil consumption will improve the oil displacement potential of EVs, while increased fuel efficiency in petroleum-fueled cars will reduce any advantage EVs might have in this connection.

A final consideration is the reduced automotive emissions and other environmental effects of EV use. Because that use would be concentrated in urban areas and the necessary increased electric power generation would be well outside of these areas, cities with oxidant problems that replace large numbers of conventional vehicles with EVs will significantly improve their air quality. This incentive could improve the prospects for EV sales and use. Emissions and other impacts of increased power generation may cancel some of this benefit, but the positive urban effects are likely to be considered the most important environmental attributes of EVs.

IF A LARGE-SCALE SYNFUELS INDUSTRY IS BUILT . . . WILL PUBLIC AND WORKER HEALTH AND SAFETY AS WELL AS THE ENVIRONMENT BE ADEQUATELY PROTECTED?

It is virtually a truism that all systems designed to produce large amounts of energy will have the *potential* to adversely affect the environment and human health and safety. It is equally true that, with few exceptions, it is technically feasible to reduce these effects to the point where they are generally considered an acceptable exchange for the energy benefits that will be obtained. In current arguments concerning synthetic fuels development, as with many other such arguments, the environmental community has focused on the potential damaging effects, while the industry has focused on the controls and environmental management procedures available to them. Gaining a perspective on the correct balance between these two points of view—on the likelihood that some of the potential damages will *actually occur* —is especially important in the case of synfuels development because environmental dangers have become a genuine public concern.

As shown in the evaluation of potential environmental impacts in this report, many of the important impacts of a large synfuels industry will be similar in kind to those of coal-fired electric power generation. The magnitude of these impacts (acid drainage and land subsidence from coal mines, emissions of sulfur and nitrogen oxides and particulates, effects of water use, population increases, etc.) is likely to be similar to and in some cases less than the likely impacts of the new, tightly controlled electric-generating capacity projected to be installed in the same time frame.

A second set of impacts—those associated with the toxic materials present in the process and waste streams of the plants and possibly in their products—are not predictable at this time but are, nevertheless, very worrisome. Factors that should be useful in gaging the risk from these impacts include the technical problems facing the designers of environmental controls, the availability of adequate regulations and regulatory agency resources, past industry and Government behavior in implementing environmental and safety controls, and difficulties that might be encountered in detecting adverse impacts and tracing them to their sources. A brief discussion of these factors follows:

1. *Technical Problems.*—Virtually all the controls which are planned for synthetic fuels plants are based on present engineering practices in the petroleum refining, petrochemical, coal-tar processing and power generation industries, and industry spokesmen appear confident that they will work satisfactorily. Problems may be encountered, however, because of differences between these industries and synfuels plants—the latter have higher concentrations of toxic hydrocarbons and trace metals, higher pressures, and more erosive process streams, in particular. As yet, few effluent streams have been sent through integrated control systems, so it has not yet been demonstrated that the various control processes will work satisfactorily in concert. Technical personnel at the Environmental Protection Agency (EPA) and the Department of Energy (DOE) have expressed particular concerns about control-system reliability.

   Judging from these indications, it appears possible that a considerable period of time—possibly even a few years—will be necessary to solve control problems in the first few plants and get the environmental systems working with adequate performance and reliability. Delays are especially likely for direct-liquefaction plants, which have some particularly difficult problems involving toxic substances and erosive process streams. These delays may be aggravated by a potential gap in control technology development. Recent Federal policy has left the development of environmental controls largely to industry. The major concern of the synfuels industry, on the other hand, is to clean up waste streams so that existing regulations may be met. Less emphasis is placed on controlling pollutants such as polynuclear aromatics that are not currently regulated. It appears certain that there will be considerable pressure to regulate these and other pollutants, but it is not certain that the industry will be able to respond quickly to such regulations.
2. *Detecting and Tracing Impacts.*—One of the major potential dangers of synfuels plants will be low-level emissions of toxic substances, especially through vapor leaks (primary danger to workers) or ground water contamination from waste disposal (primary danger to the public and the general environment). Current ground water monitoring probably is inadequate to provide a desirable margin of safety, although presumably knowledge of this danger will result in better monitoring systems. A major problem may be the long lag times associated with detecting carcinogenic/mutagenic/teratogenic damages—a major concern associated with trace hydrocarbons produced under the physical and chemical conditions present in most synfuels reactors.
3. *Regulation.*—The regulatory climate facing an emerging synfuels industry is mixed. On the one hand, ambient standards for particulates, sulfur oxides, and other pollutants

associated with conventional combustion sources are in place and should offer adequate protection to public health with respect to this group of pollutants. A limited number of other standards, including those for drinking water protection, also are in place. On the other hand, new source performance standards—federally set emission standards—have not been determined yet, nor have national emission standards for hazardous air pollutants been set for the variety of fugitive hydrocarbons or vaporized trace elements that might escape from synfuels plants. Likewise, although Occupational Safety and Health Administration (OSHA) exposure standards and workplace safety requirements do apply to several chemicals known or expected to occur in synfuels production, the majority of such chemicals are not regulated at this time.

These regulatory gaps are not surprising, given the limited experience with synfuels plants, and several of the standards—especially the emissions standards—probably could not have been properly set at this stage of industry development even had there been intensive environmental research. However, the difficulties in detecting impacts described above, and some doubts as to the availability of environmental research resources at the Federal level, lead to concern about the adequacy of future regulation.

4. *Past History.*—Given both the potential for environmental harm and the potential for mitigating measures, the attitude and behavior of both the industries that will build and operate synfuels plants and the agencies that will regulate them are critical determinants of actual environmental risk. Consequently, an understanding of the past environmental record of these entities should be a useful guide in gaging this risk. Unfortunately, there is little in the way of comprehensive research on this behavior. Even the compilation of data on compliance with existing regulations and incidence of deaths and injuries is quite weak.

For example, to our knowledge EPA has sponsored only one major evaluation of compliance with emission regulations; this recent study of nine States showed that 70 percent of all sources failed to comply fully with those regulations. Also, Department of Labor statistics on occupational hazards are compiled in such a way as to overlook health problems that cannot easily be attributed to a specific cause—just the kinds of problems of most concern to an evaluation of potential synfuels problems. Consequently, occupational health and safety statistics that appear favorable to synfuels-related industries are likely to be an inadequate guide to the actual hazard potential.

Anecdotal evidence, although not an adequate basis for evaluating risk, may be useful as a warning signal of future causes of health and safety problems. For example, recent studies have demonstrated that protective gloves used in the chemical industry fail to protect workers from several hazardous, and commonly encountered, chemicals. This points to both an immediate technical problem and an institutional failure in the chemical industry itself and its regulating agencies. On the other hand, the tests, which were sponsored by OSHA, also demonstrate the ability of the regulatory agency to correct past failures.

Another example of anecdotal evidence that may indicate some future problems with industry performance is that some developers have failed to incorporate separate and measurable control systems in synfuels pilot plants. For example, a direct-liquefaction facility in Texas has its effluents mixed with those of a neighboring refinery, rather than having a separate control system whose effectiveness at treating synfuels wastes can be tested and optimized. This might reflect industry's lack of priority or, more likely, its high level of confidence that no unusual control problems will arise that cannot be readily handled at the commercial stage. There is considerable disagreement about the validity of this confidence.

Finally, there is ample evidence that the chemical industry and its regulators have had significant problems in dealing properly with subtle, slow-acting chemical poisons. Chemicals that were unregulated or inadequately regulated for long periods of time, and whose subsequent regulation became major sources of conflict between industry and Government, include benzene, formaldehyde, vinyl chloride, tetraethyl lead, the pesticide 2,4,5-T, and many others. In some cases, controversy persists despite years or even decades of research.

An implication of the above discussion is that adequate environmental management of synfuels is unlikely to occur automatically when development begins in earnest. Although OTA believes that the various waste streams can be adequately controlled, this is going to require a strong industry effort to determine the full range of potential environmental impacts associated with development and to devise and implement measures to mitigate or prevent the important impacts. At present, however, there are indications that most developers are interested primarily in meeting current regulatory requirements, most of which are limited in their coverage of potential impacts. And completing the regulatory record, to provide the incentive necessary to stimulate further environmental efforts, is going to be a difficult and time-consuming job, particularly if ongoing cutbacks in Government research and regulatory budgets are not accompanied by promised improvements in efficiency.

Finally, there are some remaining doubts about the reliability of proposed control systems in meeting current regulatory requirements. These potential problem areas imply that Congressional oversight of an emerging synfuels industry will need to be especially vigorous in its coverage of environmental concerns.

WILL WATER SUPPLY CONSTRAIN SYNFUELS DEVELOPMENT?

In the aggregate, the water consumption requirements for synfuels development are small. Achieving a synfuels production capability of 2 million barrels per day oil equivalent would require on the order of 0.3 million acre-feet/year or about 0.2 percent of estimated total current national freshwater consumption. Nevertheless, synfuels plants are individually large water consumers. Depending on both the water supply sources chosen for synfuels development and the size and timing of water demands from other users, synfuels development could create conflicts among users for increasingly scarce water supplies or exacerbate conflicts in areas that are already water-short.

The nature and extent of the impacts of synfuels development on water availability are controversial. The controversy arises in large part because of the many hydrologic as well as institutional, legal, political, and economic uncertainties and constraints which underlie the data, and because of varying assumptions and assessment methodologies used. The importance of the factors influencing water availability will vary in the different river basins where the energy resources are located.

In the major Eastern river basins where energy resources are located (i.e., the Ohio, Tennessee, and the Upper Mississippi), water should generally be adequate on the mainstems and larger tributaries, without new storage, to support likely synfuels development. However, localized water scarcity problems could arise during the inevitable dry periods or due to development on smaller tributaries. The severity of these local problems cannot be ascertained from existing data and they have not yet been examined systematically. With appropriate water planning and management, it should be possible to reduce, if not eliminate, any local problems that might arise.

Competition for water in the West already exists and is expected to intensify with or without synfuels development. In the Missouri River Basin, the magnitude of the institutional, legal, and political uncertainties, together with the need for major new water storage projects to average-out seasonal and yearly streamflow variations, preclude an unqualified conclusion as to the availability of water for synfuels development. The major sources of these uncertainties, which are difficult to quantify because of a lack of supporting information, include Federal reserve water rights (including Indian water rights claims), provisions of existing compacts, and instream flow reservations.

In the Upper Colorado River Basin, water could be made available to support the level of synfuels development expected over the next decade. However, the institutional, political, and legal uncertainties make it difficult to determine which sources would be used and the actual amount of water that would be made available from these sources. The principal uncertainties concern the use of Federal storage, the transfer of water rights, provisions of existing compacts and treaties, and Federal reserve rights. The range of uncertainty surrounding the water availability to the entire basin after 1990 is so broad that it tends to subsume the amount of water that would be needed for expanded synfuels development.

ARE SYNTHETIC FUELS COMPATIBLE WITH EXISTING END USES?

When introducing new fuels into the U.S. liquid fuels system, it is important to determine the compatibility of the new fuels with existing end uses in order to determine what end-use changes, if any, may be necessary. In this section the compatibility of various synfuels with transportation end uses is briefly described.

Alcohols

Neither pure ethanol nor pure methanol can be used in existing automobiles without modifying the fuel delivery system, but cars using them can be readily built and engines optimized for pure alcohol use would probably be 10 to 20 percent more efficient than their gasoline counterparts. New cars currently are being built to be compatible with gasohol (10 percent ethanol, 90 percent gasoline), so potential problems with this blend are likely to disappear with time.[8] Methanol-gasoline blends have been tested with mixed results. Principal problems include increased evaporative emissions and phase separation of the fuel in the presence of small amounts of water. These problems can be reduced by blending t-butanol (another alcohol) with the methanol, and such a blend is currently being tested.[9] However, due to the corrosive effects of methanol on some plastics, rubbers, and metals in some vehicles, it probably is preferable to use methanol in its pure form in modified vehicles or to require that components in new automobiles be compatible with methanol blends.

Shale Oil

Shale oil has been successfully refined at the pilot plant level to products that meet refinery specifications for petroleum derived gasoline, diesel fuel, and jet fuel.[10] The properties of the diesel and jet fuels are shown in tables 18 and 19, where they are compared with the petroleum counterparts. Current indications are that the major question with respect to compatibility of these fuels with their end uses is what minimum level of refining (and thus refining cost) will be needed to satisfy the needs of end users.

Direct Coal Liquids

One of the direct coal liquids, SRC II, has also been successfully refined to products that meet refinery specifications for gasoline and jet fuel (tables 18 and 19). (The cetane number of the resultant "diesel fuel," however, is lower than that normally required for petroleum diesel fuel.) The gasoline, because of its aromatics content,

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[8] *Energy From Biological Processes, Volume II: Technical and Environmental Analyses*, OTA-E-128 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, September 1980).

[9] Ibid.

[10] R. A. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," third interim report, prepared for DOE under contract No. EF-76-C-01-2315, Chevron Research Co., Apr. 30, 1980.

Table 18.—Properties of Selected Jet Fuels Derived From Shale Oil and SRC-II

	Typical petroleum (Jet A)	350° to 500° F hydrotreated shale oil	300° to 535° F hydrocracked shale oil	300° to 550° F or 250° to 570° F hydrotreated SRC-II
Gravity, °API	37-51	42	47	33-36
Group type, LV%:				
Parraffins		35	55	3-4
Cycloparaffins		45	40	93-81
Aromatics	< 20	20	5	4-15
Smoke points, mm	> 20	21	35	20-23
Freeze point, ° F	−40	−42	−65	−75 to −95
Nitrogen	(a)	2	0.1	0.1

[a] In addition, severe stability requirements mean that heteroatom content must be very low (usually the nitrogen content is less than 10 ppm for petroleum-derived jet fuel).

SOURCE: R. A. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," third interim report, prepared for DOE under contract No. EF-76-C-01-2315, Chevron Research Co., Apr. 30, 1980.

Table 19.—Properties of Selected Diesal Fuels Derived From Shale Oil and SRC-II

	Typical petroleum	350° to 650° F hydrotreated shale oil	350° to 600° F hydrotreated shale oil coker distillate	350° F+ hydrotreated SRC-II
Gravity, °API	> 30	38	41	29
Cetane No.	> 40	46[a]	48	39
Pour point, ° F	<+15	−5	−20	−55
Group type, LV%:				
P		37	41	−4-7
N		44	41	70-93
A		19	18	2-23
Nitrogen, ppm[b]	(b)	350	350	0.1-0.5

[a] Estimated.

[b] Heteroatoms must be removed to level required for stability (usually 500 ppm N for petroleum).

SOURCE: R. A. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," third interim report, prepared for DOE under contract No. EF-76-C-01-2315, Chevron Research Co., Apr. 30, 1980.

would be used as an octane-enhancing blending agent in conventional gasoline. Aromatics, such as benzene and toluene, are currently used for this purpose in gasoline. Again, a principal question is what minimum level of refining will be needed. Other direct coal liquids probably are similar to SRC II liquids.

Indirect Coal Liquids

Other than methanol, which was considered above, the principal indirect coal liquids for ground transportation are gasolines, although the Fischer-Tropsch (FT) processes can be arranged to produce a variety of distillate fuels, as well. There are no indications that these gasolines would not be compatible with the existing automobile fleet, either alone or in blends with conventional gasoline.

Caveat

Despite the apparent compatibility of hydrocarbon synfuels with existing end uses, refinery specifications do not uniquely determine all of the properties of the fuel. The tests used to characterize hydrocarbon fuels were designed for petroleum products and may be inadequate indicators for the synfuels. Some potential problems with the hydrocarbon synfuels that have been mentioned include:

- *Lubrication.*—Hydrotreating of synfuels is necessary to meet refinery specifications. However, the lubricating properties of the synfuels drop with this hydrotreating. This drop in lubricity could lead to possible problems with fuel-injection nozzles and other moving parts that rely on the fuel for lubrication.

- *Emissions.*—The particulate and nitrogen oxide emissions of synthetic diesel fuel could be greater than those from an otherwise comparable petroleum diesel fuel. Automobile manufacturers are having difficulty meeting emissions standards with conventional diesel fuel, and there is some concern that synfuels could aggravate these problems.
- *Variability.*—The direct liquefaction synfuels from coal can vary in composition depending on the coal used.[11] Consequently, although the synfuel from one coal may be compatible with an end use, the same process might produce an incompatible synfuel if another coal is used.

In principle, if the exact chemical composition of synfuels were known, synfuels could be blended from petrochemicals and tested extensively for these potential problems before synfuels plants were built. In practice, however, the chemical compositions are so complex, varied, and process-dependent that this option is probably not practical.

The alternative is to wait until sufficient quantities of synfuels are available and to conduct extensive field tests of synfuels processed in various ways and from different coals. Until this is done, statements about the compatibility of hydrocarbon synfuels with current end uses are somewhat speculative.

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[11] Ibid.

Chapter 5

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Chapter 5

Increased Automobile Fuel Efficiency

STATUS AND TRENDS

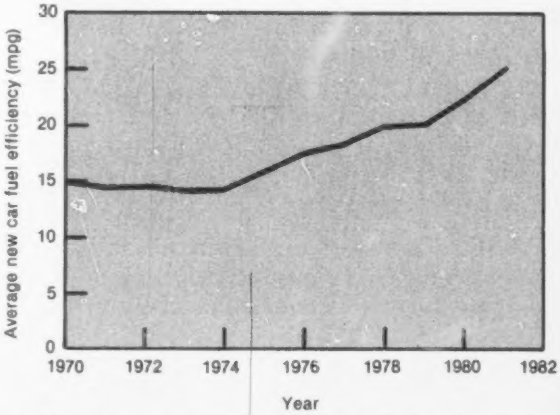
Until the 1970's, fuel economy was seldom important to American car buyers. Gasoline was cheap and plentiful, taxes on fuel and on car size low. In contrast with automobile markets in most of the rest of the world, automakers had few incentives to build small cars, or consumers to purchase them. The typical American passenger car —large, comfortable, durable—evolved in relative isolation from design trends and markets in other parts of the world. Fuel economy was a minor consideration. (This was not the case for heavy trucks, where fuel costs have always been a substantial component of operating expenses.)

In the late 1960's and early 1970's, Federal emissions control standards worked at the expense of fuel economy. But fuel economy pressures were also building—signified by gasoline shortages, the sudden rise in oil prices, and the passage of the Energy Policy and Conservation Act of 1975 (EPCA). EPCA set fleet average mileage standards for automobiles sold in the United States beginning in 1978. The combination of Corporate Average Fuel Economy (CAFE) standards and market forces stimulated rapid changes in the design of American cars, followed by a sharp swing in consumer demand during 1979 and 1980 toward small, economical imports.

A similar upsurge in small-car demand had followed the 1973-74 oil shock. Over the 1965-75 period, American-made cars averaged about 14 to 15 miles per gallon (mpg).* For model year 1980, the average for cars sold in the domestic market was up to 21 mpg, 1 mpg above the EPCA requirement. For 1981 models, domestic cars sold through January 5, 1981, averaged almost 24 mpg, or almost 2 mpg above EPCA requirements. (See also fig. 6.)

Most of the increases in fuel economy have come from downsizing—redesigning passenger cars so that they are smaller and lighter, and can use engines of lower horsepower. Other changes in vehicle design—e.g., decreased aerodynamic drag and rolling resistance, improved automatic transmissions and higher rear axle ratios, electronic engine controls, greater penetration of diesels—have also helped to reduce fuel consumption.

Figure 6.—Historical Average New-Car Fuel Efficiency of Cars Sold in the United States



SOURCE: J. A. Foster, J. D. Murrell, and S. L. Loos, "Light Duty Automotive Fuel Economy . . . Trends Through 1981," SAE Paper 810386, February 1981.

While the latest technology is used in these redesigns, technology itself is not—and has not been—a limiting factor in passenger-car fuel economy in any fundamental sense. The limiting factor is what the manufacturers decide to build based on judgments of future consumer demand. Decisions on new models may also be constrained by the costs of new capital investment. Technology does have a vital role in managing the many tradeoffs among manufacturing and investment costs, fuel economy, and the other attributes that affect consumer preferences—quality, comfort, carrying capacity, driveability, and performance. Technology is also critical in managing possible tradeoffs involving fuel economy, emissions, and safety.

American automakers are still incrementally downsizing their fleets—in the process converting to front-wheel drive, which helps to preserve interior space. These redesigns have been largely paced by three interrelated factors: 1) CAFE standards, which require fleet averages of 27.5 mpg by 1985; 2) each manufacturer's estimates of future market demand in the various size classes (until 1979, market demand for smaller, more fuel-efficient cars lagged behind the CAFE standards, but it has now outstripped them—several recent projections point toward fleet averages of more than 30 mpg by 1985[1]); and, 3) the capital resources of U.S. firms, which affect both their ability to design and develop new small cars and their ability to invest in new plant and equipment for manufacturing them.

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*Based on EPA's combined test cycles (55 percent city and 45 percent highway cycle).

The gradual downsizing of the U.S. automobile fleet has been accompanied by an intensive developmental effort aimed at maximizing the fuel economy of cars of a given size, consistent with the need for low pollutant emission levels and occupant safety—both also matters of Government policy. Foreign manufacturers, who in 1980 accounted for about one-quarter of sales in the United States, are also improving the fuel economy of their fleets, but they can concentrate on technical improvements rather than new small-car designs because their product lines are already heavily oriented toward cars that are small in size and low in weight.

Because the U.S. automobile fleet now contains over 100 million cars, increases in new-car fuel economy take time to be felt. Typically, about half the cars of a given model year are still on the road after 10 years; it takes about 17 years before 99 percent are retired. Thus, while new-car fuel economy for the 1980 model year reached about 21 mpg, the average for the U.S. fleet in 1981 is still only about 16 to 17 mpg, a legacy of the big cars of earlier years. If new cars average 30 to 35 mpg by 1985—a target that is easily attainable from a technological standpoint—the average fuel efficiency of cars on the road would reach only about 22 mpg by 1985. While more than half the annual fuel savings associated with the 1985 CAFE standards will be achieved by 1985, the full benefit of the 30-mpg new cars of 1985—and of further improvements in later years—will not come until the end of the century.

Of course, 30-mpg CAFE standards are possible right now, and 50-mpg cars are currently being sold. Proportionately higher fuel economy figures will in principle be attainable in the future, as automotive technology progresses. But today only a portion of consumers want such vehicles—because fuel economy often comes at the expense of comfort, accommodations for passengers and luggage, performance, luxury, convenience features and accessories, and other attributes more commonly found in larger cars—and manufacturers try to plan their future product mix to appeal to a broad range of consumer tastes.

The sudden shift in market demand toward small, fuel-efficient cars in 1974-75, followed by a resurgence in large-car sales during 1976-78 and another wave of demand for fuel efficiency in 1979 and 1980, illustrates the unpredictable nature of consumer preferences. The 1979 market shift has outpaced the CAFE standards. The 27.5-mpg requirement set by EPCA for the 1985 model year remains in effect for subsequent years unless modified by Congress. If world oil prices again stabilize, and supply exceeds demand—as occurred through much of 1981—the risks and uncertainties facing U.S. automakers could multiply, a particularly worrisome situation given their precarious financial situations and the large capital outlays necessary for redesign and retooling. Recently, American automakers have been reassessing their commitments to rapid downsizing and new small-car lines—both because of cash flow shortfalls and because of uncertainty over future market demand.[2]

The 14-mpg U.S. fleet average of 1975 is a useful baseline for estimating recent and near-term fuel savings resulting from the combination of EPCA standards and market forces. For the period 1975-85, OTA estimates that fuel economy increases in passenger cars alone will have saved slightly more than 0.8 MMB/DOE (million barrels per day, oil equivalent) on the average—much less in the earlier years, and about twice as much near the end of this 10-year period. Considering only passenger cars, the cumulative saving through 1985 will be approximately 3 billion barrels (bbl) of petroleum—about 75 percent of the total U.S. crude oil imports during 1979 and 1980. For the period 1985-95, by the end of which the average efficiency of all cars on the road should be 30 mpg or more, the daily savings would be at least 3 million barrels per day (MMB/D), giving an additional cumulative saving of at least 10 billion bbl compared with a 14-mpg fleet. Thus, for the 20-year period 1975-95, the total savings from increased passenger-car fuel economy would be over 13 billion bbl—equivalent to 8 years of crude oil imports or about 7 years of net petroleum imports at the 1981 rate.

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[1] W. G. Agnew, "Automobile Fuel Economy Improvement," General Motors Research Publication GMR-3493, November 1980; *The U.S. Automobile Industry, 1980: Report to the President From the Secretary of Transportation*, DOT-P-10-81-02, January 1981. Independent estimates by OTA are similar.

[2] J. Holusha, "Detroit's Clouded Crystal Ball; Gasoline Glut Spurs Review of Small Cars," *New York Times*, July 28, 1981, p. D1; J. Holusha, "For G.M., a Fresh Look at Spending Strategy," *New York Times*, Nov. 10, 1981, p. D1.

These estimated reductions in petroleum consumption could be larger if fuel-economy improvements proceed faster than assumed. Fuel-economy improvements in trucks, particularly light and medium trucks, will also save significant amounts. Nonetheless, the U.S. passenger-car fleet would still consume 3.6 MMB/D in 1985 and 3 MMB/D in 1995—compared with 4.3 MMB/D in 1980—if the passenger-car fleet grows as expected and cars continue to be driven at the historical rate of 10,000 miles per year, on the average. If automobile travel is reduced, fuel consumption would be decreased proportionately.

The savings in petroleum consumption—which represent a direct benefit to consumers as well as an indirect benefit because of the expected improvement in the U.S. balance of payments—also carry costs. These will generally take the form of higher purchase prices for new cars, even though these cars will be smaller. Costs will be higher because the redesign and retooling for a downsized U.S. fleet requires capital spending at rates significantly higher than the historical average for American manufacturers. Increased capital spending—which, along with the sales slump of 1979-81, shares responsibility for the over $4 billion lost by U.S. automakers during 1980—is passed along at least in part to purchasers. To the extent that competitive forces allow, importers will also raise prices even though their capital spending rates may not have gone up.

Many of the technological roads to improved fuel economy also carry higher direct manufacturing costs. A familiar example is the diesel engine—which, for comparable performance, can increase passenger car fuel economy, and decrease operating costs, by as much as 25 percent, but at a substantial penalty in purchase price. In this case, the higher costs stem largely from an intrinsically expensive fuel injection system, but also from the greater mechanical strength and bulk required in a diesel engine. Beyond economic costs and benefits, smaller cars cannot be designed to be as safe as larger cars (given best practice design in both)—thus, risks of death and injury in collisions could go up.

For the 10-year period 1968-77, average annual capital investment by the big three U.S. automakers in constant 1980 dollars was $6.68 billion[3] (AMC and, in later years, Volkswagen of America add only small amounts to these averages). Over this period, production fluctuated considerably, but with only a slight upward trend; thus, the average expenditure is primarily that for normal redesign and retooling as new models are introduced and existing product lines updated, rather than for increases in production capacity. Note that the period 1968-77 includes investments associated with the introductions of several new small cars around 1970 (Pinto, Maverick, Vega), as well as later subcompact designs (Chevette, Omni/Horizon). The figures also include overseas investments by the three U.S. firms.

The 2 years with the highest investments during the 1968-77 period were 1970 ($7.67 billion) and 1977 ($7.78 billion). In 1978, investment rose to $9.21 billion, and in 1979 it reached $10.5 billion (still in 1980 dollars)—half again as much as the historical level. (See fig. 7.) Estimates of investment for the 5-year period 1980-84 reach close

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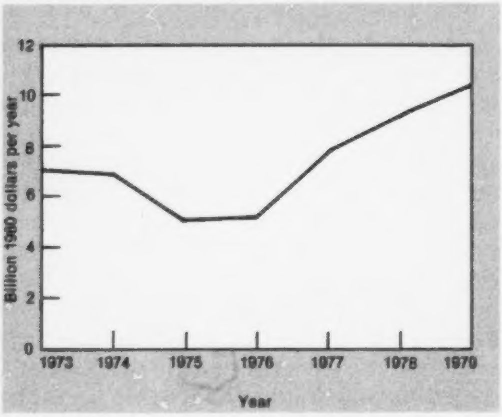
[3] These investment figures were tabulated from annual reports by R. A. Leone, W. J. Abernathy, S. P. Bradley, and J. A. Hunker, "Regulation and Technological Innovation in the Autombile Industry," report to OTA under contract No. 933- 3800.0, May 1980, pp. 2-92. Conversions to 1980 dollars are based on the implicit price deflator for nonresidential fixed domestic investment.

Figure 7.—Historical Capital Expenditures by U.S. Automobile Manufacturers



SOURCE: G. Kulp, D. B. Shonka, and M. C. Holcomb, "Transportation Energy Conservation Data Book: Edition 5," Oak Ridge National Laboratory, ORNL-5765, November 1981.

to $60 billion.[4] [5] Such estimates have generally been based on fleet redesigns to meet EPCA requirements through 1985. While it is doubtful that they include much spending for new models to be introduced in the immediate post-1985 period, they do include substantial overseas expenditures —perhaps one-quarter or more.

The $60 billion estimate represents about $12 billion per year in 1980 dollars, nearly double the historical spending level. It is a clear indication of the market pressures (for smaller cars as well as for greater fuel economy in vehicles of all sizes, including light trucks) being placed on domestic manufacturers. Component suppliers also face higher-than-normal investments.

The remainder of this chapter treats the factors that determine automobile fuel consumption in more detail—both the technological factors and market demand—as well as the net savings in fuel consumption that may accrue from increases in automobile fuel economy. While consumer preferences—as judged by manufacturers in planning their future product lines—are dominant, technology is vital in maximizing the fuel economy that can be achieved by cars of given size and weight, as well as given levels of performance, emissions, and occupant safety.

AUTOMOBILE TECHNOLOGIES

Fuel consumed by an automobile (or truck) depends, first, on the work (or power) expended to move the vehicle (and its passengers and cargo), and second, on the efficiency with which the energy contained in the fuel (gasoline, diesel fuel) is converted to work. The power requirements depend, in essence, on: 1) the driving cycle—the pattern of acceleration, steady-state operation, coasting, and braking—which is affected by traffic and terrain, but otherwise controlled by the driver; 2) the weight and rolling resistance of the vehicle; and 3) the aerodynamic drag, which depends on both the size and shape of the vehicle and is also a function of speed. The designer controls weight, aerodynamic drag, and to some extent the rolling resistance, but can affect the driving cycle only indirectly—e.g., through the power output and gear ratios available to the driver.

The fuel consumed in producing the power to move a vehicle of given size and weight is again a function of vehicle design, primarily engine design. The *efficiency* with which the engine converts the energy in the fuel to useful work depends on the type of engine as well as its detail design; diesel engines are more efficient than spark-ignition (gasoline) engines, but not all diesel engines have the same efficiency.

Furthermore, an engine's efficiency varies with load. For example, when a car is idling at a traffic light, the engine's efficiency is virtually zero because the energy in the fuel is being used only to overcome the internal friction of the engine and to power accessories. Engines are more efficient at relatively high loads (accelerating, driving fast, or climbing hills), but such operation will still use fuel at a high rate simply because the power demands are high—hence the justification for the 55-mph speed limit as an energy-conservation measure.

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[4] General Accounting Office, "Producing More Fuel-Efficient Automobiles: A Costly Proposition," CED-82-14, Jan. 19, 1982.

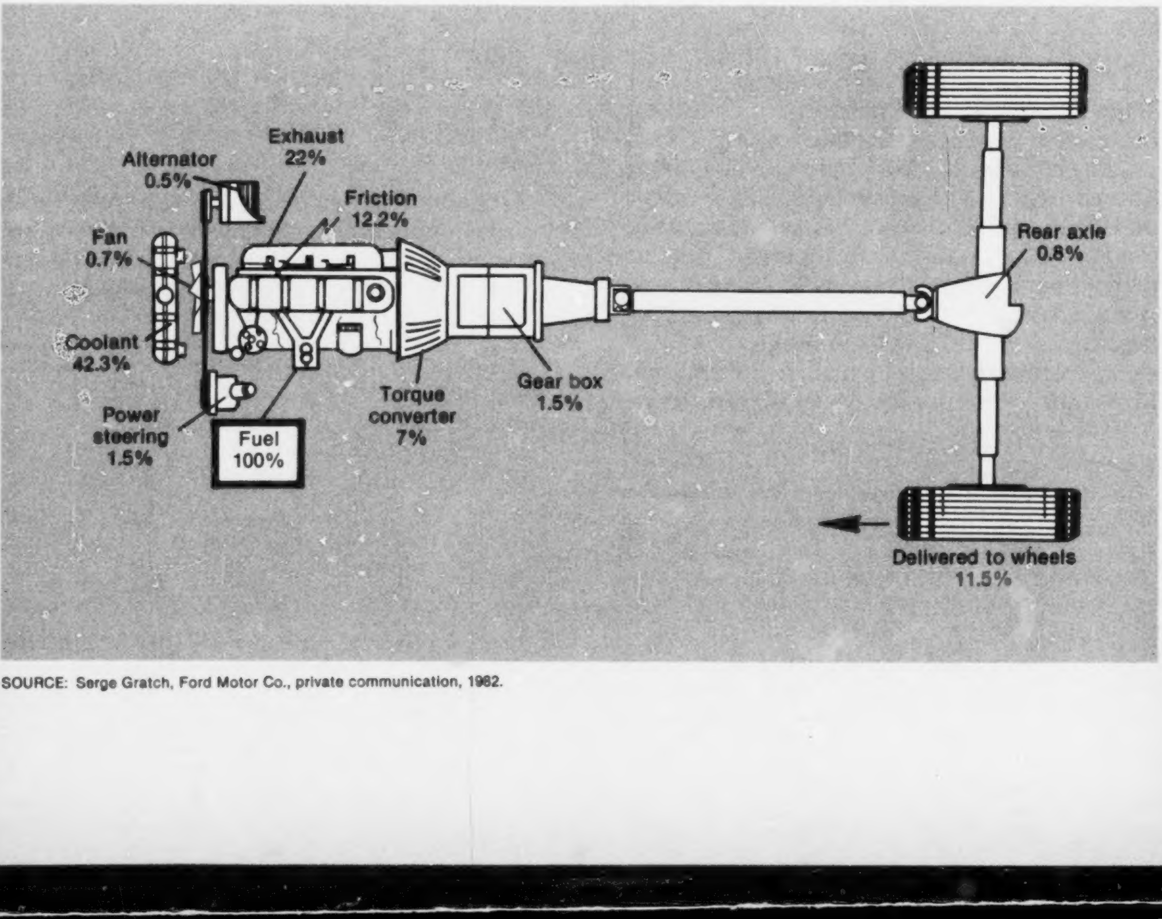
[5] *Fuel Economy Standards for New Passenger Cars After 1985* (Washington, D.C.: Congressional Budget Office, December 1980), p. 56. Other estimates are generally comparable but may differ as to whether development costs or only fixed investment are included.

Efficiency—the fraction of the fuel energy that can be converted to useful work—cannot be 100 percent in a heat engine for both theoretical and practical reasons. For a typical automobile engine, *peak* efficiency may exceed 30 percent, but this is attained for only a single combination of load and speed. *Average* efficiencies, characteristic of normal driving, may be only 12 or 13 percent, even lower under cold-start and warmup operation. To illustrate this point, figure 8 shows energy losses for the drivetrain in one 1977 model car in the Environmental Protection Agency's (EPA) urban cycle. This figure should not be taken too literally because losses vary considerably from car to car and numerous design changes have been implemented since 1977, but the figure does serve to illustrate approximate magnitudes.

The design of the engine affects the amount of fuel consumed during the driving cycle in two basic ways. First, the size of the engine fixes its maximum power output. In general, a smaller engine in a car of given size and weight will give better fuel economy, mainly because the smaller engine will, on the average, be operating more heavily loaded, hence in a more efficient part of its range. There are practical limits to engine downsizing, however, because a heavily loaded, underpowered engine provides poor performance and can suffer poor durability.

Second, the designer can directly affect driving-cycle fuel economy through the transmission and axle interposed between the engine and wheels. Significant gains in fuel economy over the past few years have come from decreases in rear axle

Figure 8.—Fuel Use in City Portion of EPA Fuel-Efficiency Test Cycle (2,750 lb/2.3 liter)



SOURCE: Serge Gratch, Ford Motor Co., private communication, 1982.

ratios* so that engines are operating at higher efficiencies during highway operation, and from changes in transmission ratios** to better match driving needs to engine efficiency (in earlier years transmission ratios were often chosen to maximize performance rather than fuel economy). Adding more speeds to the transmission—whether manual or automatic—serves the same objective. The optimum would be a continuously variable, stepless transmission allowing the engine to operate at all times at high loads where its efficiency is greatest. (Such transmissions can be built today, but require further development for widespread use in cars.)

Changes in many other areas of automobile design can help increase fuel economy, but the primary factors are size (which is one of the factors that determines aerodynamic drag), weight (which determines the power needed for acceleration, as well as rolling resistance), and powertrain characteristics (engine plus transmission). These are discussed in more detail below, in the context of the driving cycle—itself a critical variable in fuel economy—followed by brief discussions of emissions and safety tradeoffs, methanol-fueled vehicles, and electric vehicles (EVs).

Vehicle Size and Weight

On a sales-averaged basis, the inertia weight of cars sold in the United States during 1976 (including imports) came to slightly over 4,000 lb.[6] This corresponds to an average curb weight*** of 3,700 to 3,800 lb. The average inertia weight for 1981 is expected to be about 3,100 lb, and may further decrease to around 2,750 lb by 1985. Although the lightest cars sold here still have inertia weights close to 2,000 lb—as they did in 1975—the distribution has shifted markedly toward the lower end of the range. Many heavier models have disappeared; consumers are now selecting smaller and lighter vehicles—downsized or newly designed U.S. models as well as imports.

While size is a primary determinant of weight, newer designs typically make greater use of lightweight materials such as plastics and aluminum alloys, as well as substituting higher strength steels—in thinner sections—for the traditional steels. Materials substitution for weight reduction will continue, but is constrained by the higher costs of materials with better strength-to-weight or stiffness-to-weight ratios. As production volumes go up, costs of at least some of these materials will tend to decline.

Weight is a fundamental factor in fuel economy because much of the work, hence energy, needed for a typical driving cycle is expended in accelerating the vehicle. The fuel consumed in stop-and-go driving is directly related to the loaded weight of the car (including passengers and payload) and the inertia of its rotating parts. Everything else being the same, it takes twice as much energy to accelerate a 4,000-lb car as a 2,000-lb car over the same speed range. Urban driving, in particular, consists largely of repeated accelerations and decelerations; thus, weight is critical to fuel consumption. (This also points up the potential that smoothing flows of traffic offers for gasoline savings.) Lighter cars consume less fuel even at constant speeds because they have less rolling resistance.

Although the weights of cars can be reduced by making them from lightweight materials and by shifting from separate body and frame designs to unitized construction, cars can always be made lighter by making them smaller.

Small cars can also have lower aerodynamic drag, because drag depends on frontal area as well as on the shape of the vehicle. Drag can be reduced by making cars lower and narrower, as well as by streamlining the vehicle. Drag reduction has become at least as important as styling in recent years; working primarily with wind tunnel data, automakers have reduced typical drag coefficients* from 0.5 to 0.6, characteristic of the

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*Rear axle ratio is the ratio of the drive shaft speed to the axle speed.

**Transmission ratio is the ratio of the engine crankshaft speed to the drive shaft speed.

[6] J. A. Foster, J. D. Murrell, and S. L. Loos, "Light Duty Automotive Fuel Economy . . . Trends Through 1981," Society of Automotive Engineers Paper 810386, February 1981. Inertia weight is a representative loaded weight—equal to curb weight, which includes fuel but not passengers or luggage, plus about 300 lb—used by EPA for fuel economy testing.

***Curb weight is the weight of the car with no passengers or cargo.

*The drag coefficient is a measure of how aerodynamically "slippery" the car is. The aerodynamic drag is proportional to the drag coefficient, the frontal area and the velocity squared.

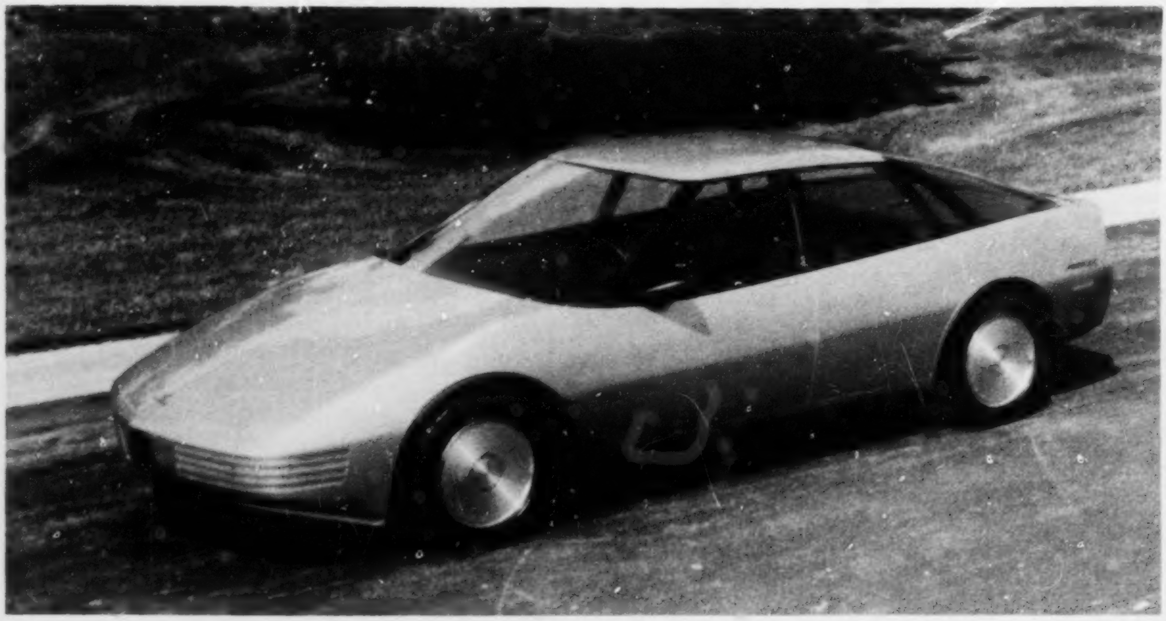

Photo credit: General Motors Corp

The shape of this experimental car is designed for low aerodynamic drag

early 1970's, to 0.4 to 0.5 at present, with a number of models being under 0.4. Values in the range of 0.35 will eventually be common.

It takes only 15 or 20 horsepower to propel a typical midsized car at a steady 55 mph—that is all that is needed to overcome rolling resistance and aerodynamic drag. The remainder of the engine's rated power is used for acceleration, climbing hills, and other demands. The low power requirements for constant-speed driving—typically 15 to 20 percent of the engine rating—emphasize the importance of the fuel used in start-and-stop driving (and the influence of weight) in determining driving-cycle fuel economy.

Powertrain

The engine (or other vehicle prime mover) converts the energy stored in fuel (or, for an EV, in batteries) to mechanical work for driving the wheels. The efficiency of the engine—as well as the efficiency of the transmission—determines the proportions of the energy in the fuel which are, respectively, used in moving the car and lost as waste heat. Under most operating conditions, transmissions are much more efficient than the engine.

The efficiency—work output divided by energy input—of any engine depends on both detail design and fundamental thermodynamic limitations. The temperatures at which the engine operates place practical constraints on the efficiencies of some types of engines—e.g., gas turbines—but not on others—e.g., spark-ignition (SI) (gasoline) and compression-ignition (CI) (diesel) engines where the combustion process is intermittent. The components of the latter need not withstand temperatures as high as those where combustion is continuous.

Many other factors besides efficiency enter into the choice of engine for a motor vehicle; until recently, efficiency was often of secondary importance. Cars and trucks have been powered by gasoline or diesel engines because these have favorable combinations of low cost, compact size, light weight, and acceptable fuel economy. Neither demands for improvements in exhaust emissions nor for better fuel economy have yet resulted in serious challenge to these engines—which have been dominant for 70 years. At least through the end of the century, most passenger cars are likely to be powered by reciprocating SI or diesel engines.

SI and CI or diesel engines have peak efficiencies generally in the range of 30 to 40 percent. However, their efficiency at *part-load* can be much less; the farther the engine operates from the load and speed for which its efficiency is greatest, the lower the efficiency. In typical urban driving, the *average* operating efficiency is less than one-third of the peak value—e.g., in the range of 10 to 15 percent.

Part-load fuel economy remains a more critical variable for an automobile engine than maximum efficiency because of the light loading typical of most driving. Such a requirement favors CI engines, for example, but works against gas turbines. CI engines have good part-load efficiency because they operate unthrottled, thereby avoiding pumping losses. They also have high compression ratios—which, up to a point, raises efficiency under all operating conditions.

Various modifications to SI engines can increase part-load efficiencies. This is one of the advantages of stratified-charge engines—which use a heterogeneous fuel-air mixture to allow overall lean operation, ideally without throttling as in a diesel—and also of SI engines that burn alternative fuels such as alcohol or hydrogen. Smaller, more heavily loaded SI engines also tend to have greater driving-cycle fuel economy because the higher loads mean the engine is running with less throttling. Among the steps that can be and are being taken to give greater fuel economy are:

- using the highest compression ratio consistent with available fuels;
- refined combustion chamber designs, particularly those optimized for rapid burning of lean mixtures, one of the routes to higher compression ratios;
- minimizing engine friction;
- optimizing spark timing consistent with emissions control;
- minimizing exhaust gas recirculation consistent with emissions control;
- precise control of fuel-air ratio, both overall and cylinder-to-cylinder, particularly under transient conditions such as cold starts and acceleration—again consistent with emissions control; and
- minimizing heat losses.

Transmission efficiencies also depend on load, but much less so than engines; transmission efficiencies are also much higher in absolute terms. For manual transmissions, more than 90 percent of the input power reaches the output shaft except at quite low loads. Because they have more sources of losses, automatic transmissions are less efficient, particularly those without a lockup torque converter or split-path feature. In these older transmissions, all the power passes through the torque converter, even at highway cruising speeds. The resulting fuel-economy penalty, compared with a properly utilized manual transmission, is typically in the range of 10 to 15 percent. By avoiding the losses from converter slippage at higher speeds, split-path or lockup designs cut this fuel-economy penalty approximately in half, four-speed transmissions offering greater improvement than those with only three forward gears.

One function of the transmission is to keep the engine operating where it is reasonably efficient. Although automatic transmissions are less efficient than manual designs, they can sometimes increase overall vehicle efficiency by being "smarter" than the driver in shifting gears. Further benefits are promised by improved electronic control systems for automatics. These microprocessor-based systems can sense a greater number of operating parameters, and are thus able to use more complex logic, perhaps in conjunction with an engine performance map stored in memory. Such control systems could also be used with manual transmissions—e.g., to tell the driver when to shift. A continuously variable transmission would be better still. As mentioned above, these can be built now, but they have not been practical because of problems such as high manufacturing cost, low efficiency, noise, and limited torque capacity and durability.

Fuel Economy—A Systems Problem

An automobile is a complex system; design improvements at many points can improve fuel economy. Even if each incremental improvement is small, the cumulative effect can be a big increase in mileage. Interactions among the elements of the system (engine, transmission, vehicle weight) and the intended use of the vehicle are among the keys to greater system efficiency. At the same time, as the state of the art improves, further increases in efficiency tend to become more difficult unless there are dramatic technical breakthroughs—and OTA thinks such breakthroughs are improbable. This is a mature technology in which, as a general rule, radical changes are few and far between.

Making cars smaller and lighter helps in many ways to reduce the power needed, hence fuel consumed. Front-wheel drive preserves interior space while allowing exterior size and weight to be reduced. Reductions in the weight of the body structure mean that a smaller engine will give equivalent performance, while also allowing lighter chassis and suspension members, smaller tires and brakes, and related secondary weight savings. Among other steps taken in recent years have been the adoption of thinner, hence lighter, window glass—and even redesigned window lift mechanisms.

Once major decisions have been made concerning overall vehicle design parameters—size, engine type, etc.—subsystem refinement and systems integration become the determining factors in the fuel economy achieved in everyday driving. Some of these refinements decrease the need for power, as by reducing friction or making accessories more efficient; others increase the efficiency of energy conversion, as by using three-way exhaust catalysts and feedback control of the fuel-air ratio to limit emissions while preserving fuel economy.

Tradeoffs With Safety and Emissions

Government policies to increase automobile fuel efficiency, reduce pollutant emission levels, and improve passenger safety involve significant tradeoffs. Measures to control auto emissions can impair fuel efficiency. Reducing the size of cars to increase fuel economy makes them intrinsically less safe. Meeting regulatory goals also affects manufacturing costs. Tradeoffs like these have not always been fully recognized in the formulation of Federal policy,[7] but will continue to be important as policymakers focus on questions of post-1985 fuel economy.

The issues include whether Government policies are to be directed at further improvements in mileage, such as by a continued increase in CAFE standards, or by a gasoline tax, and whether emissions standards are to be tightened or relaxed. The tradeoffs will involve manufacturing costs, as always—but the relationship of fuel economy to safety will perhaps be most critical.

Safety

The tradeoffs between fuel economy and occupant safety are largely functions of vehicle size—therefore of weight as well. Although many characteristics of the car are important for occupant safety, protection in serious collisions depends quite substantially on the crush space in the vehicle structure and on the room available within the passenger compartment for deceleration. Penetration resistance is also vital. Design requirements are based on a "first collision" between vehicle and obstacle, and a "second collision" between occupants and vehicle. In the "first collision," the more space available for the structure to crush—without encroaching on the passenger compartment—the slower the average rate of deceleration that the passenger compartment and the passengers experience. More crush space translates directly to lower decelerations.

Space, hence vehicle size, is also important *within* the passenger compartment. The more space available inside, the easier it is to preserve the basic integrity of the structure and the slower the occupants can be decelerated during the "second collision." Seatbelts, for example, can stretch to lower the decelerations the restrained occupants experience, but only if there is nothing rigid for the occupants to hit; deformable anchors for seatbelts are thus a further method for improving safety.

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[7] *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles*, OTA-ISC-135 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1981), pp. 120-122.

Because of their larger crush space and interior volume, big cars can *always* provide more protection for their occupants in a collision—*given best practice design.* However, not all cars embody best practice designs, and the crashworthiness of autos in the current fleet does not improve uniformly and predictably with vehicle size. Furthermore, vehicle safety depends on avoiding crashes as well as surviving them, and therefore on factors such as braking and handling as well as driver ability. These and other factors related to the potential effects on auto safety of increasing fuel efficiency are discussed in chapter 10.

Emissions Control

Fairly direct tradeoffs exist between engine efficiency and several of the measures that can be used to control the constituents of exhaust gases that contribute to air pollution. The three major contributors in the exhaust of gasoline-fueled vehicles, all regulated by the Clean Air Act and its amendments, are hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_X).[8] Emissions control measures have frequently worked against the fuel economy of cars sold in the United States since 1968, when manufacturers began to retard spark timing to reduce HC emissions. Although the costs of emissions control measures—as reflected in the purchase price of the vehicle—have often been disputed and remain controversial, there have also been operating cost penalties because fuel economy has been less than it would otherwise have been.

Mileage penalties were more severe in the mid-1970's than at present, but efficiency increases have come at the expense of higher first cost. Ground is periodically lost and regained, but even with best practice technology at any given time, the engineering problems of balancing emissions and fuel economy at reasonable cost have forced many compromises. One recent estimate of the net effect of emissions control through 1981 finds a 7.5-percent fuel-economy penalty.[9]

The single change with the greatest continuing effect has been reduced compression ratios resulting from the changeover to unleaded gasoline. CI engines *require* high compression ratios; SI engines, in contrast, suffer from a form of combustion instability termed detonation (i.e., the engine "knocks") if the compression ratio is too high for the octane rating of the fuel. Thus, decreases in the already lower compression ratios of SI engines—to values in the range of 8:1 versus ratios as high as 10:1 in the early 1970's—have led to significant decreases in fuel economy.

Lead compounds, formerly added to gasoline to raise the octane, have been removed to prevent poisoning (deactivation) of catalytic converters—themselves adopted to control, first, HC and CO, and later NO_X as well—and also because of concern over the health effects of lead compounds. While electronic engine control systems, including knock detectors, have allowed compression ratios to be increased somewhat, only a portion of the ground lost can be regained in this way.

Methanol with cosolvents can be used as an octane-boosting additive to gasoline that does not interfere with the catalytic converter. In addition, compact, fast-burn combustion chambers may help. By burning the fuel fast enough that the preflame reactions leading to detonation do not have time to occur, fast-burn combustion systems might allow compression ratios to be increased by several points. This latter approach, however, increases HC and NO_X emissions, and it is not yet clear how much compression ratios can be raised while maintaining emissions within prescribed limits.

Related measures used to control emissions—and/or to limit detonation—can also degrade engine efficiency. Retarding ignition timing—to limit detonation, and in some cases help control HC and CO emissions by promoting complete combustion of the fuel—hurts fuel economy. Other techniques adopted in the early 1970's to control HC and CO—such as thermal reactors, which were likewise intended to drive the combustion process toward complete reaction of HC and CO —also led to increased fuel consumption.

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[8] D. J. Patterson and N. A. Henein, *Emissions From Combustion Engines and Their Control* (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1972).

[9] L. B. Lave, "Conflicting Objectives in Regulating the Automobile," *Science,* May 22, 1981, p. 893.

Unfortunately, while more complete combustion decreases HC and CO pollutants, NO_x in the exhaust is *increased* under conditions leading to more complete combustion. Thus, not only does control of exhaust emissions conflict with fuel economy, but there are also potential conflicts between control of HC and CO on the one hand, and NO_x on the other. The NO_x standards of the mid-1970's could be met by adding exhaust gas recirculation (EGR) to the repertoire of measures used for HC and CO control. Although EGR initially carried a substantial fuel economy penalty, and also impaired driveability, improved control systems—which recirculate exhaust only when needed—have improved both economy and driveability substantially. Still, the drawbacks of other methods of NO_x control,* together with the more stringent NO_x standards of later years, have led to the most common current control technique—the three-way catalytic converter, which reduces levels of all three pollutants. This gives fuel economy comparable to an uncontrolled engine, though at higher first cost.

Compression ratios of diesel engines are often twice those for SI engines; at these high levels small changes in compression ratio have relatively little effect on efficiency. For this reason and because of the different set of emissions standards applied, CI engines have faced fewer conflicts between emissions control and fuel economy. This advantage has helped them to compete with SI engines for passenger cars, although the situation may change in the future, as the diesel standards become tougher. Particulates (bits of unburned, charred fuel) are the most difficult of diesel emissions to control, although NO_x also poses problems. However, future regulations for particulates in diesel exhaust are not yet definite. This creates uncertainty not only about the control technologies that might be needed, but also about the future penetration of CI engines in passenger vehicles.

Nonetheless, as will be seen below, OTA remains cautiously optimistic about diesels. Their higher intrinsic efficiency at both full- and part-load makes them quite attractive in terms of fuel economy, and there is considerable scope for further improvements in their driveability and related characteristics that are more important for passenger cars than for trucks and other uses in which diesels have been more common. The long developmental history of CI engines provides a useful foundation for passenger-car applications.

Methanol-Fueled Engines

There are basically two routes to higher SI engine efficiency via alternate fuels: lean operation, which cuts pumping and other thermodynamic losses, and higher compression ratio.[10] Fuels vary in the extent to which these factors operate and there are a number of secondary effects, but alcohols and hydrogen have excellent potential for both lean burning and higher compression ratios, with possible driving-cycle economy improvements in the range of 10 to 20 percent. Further engineering development—but no breakthroughs —would be needed before alcohols or other alternate fuels could be used in U.S. cars, but the production and distribution of such fuels are more significant barriers.

Diesels, like SI engines, can operate on a variety of alternative fuels, although perhaps needing spark-assisted combustion. Powerplants such as open-chamber stratified-charge engines and continuous combustion engines can often tolerate quite broad ranges of fuels with minimal design changes.

Because methanol from coal is an attractive synthetic fuel, methanol-burning engines for passenger cars are discussed in more detail below. Unlike ethanol, which will probably be used primarily as a gasoline extender (e.g., in gasohol),

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*It should be noted, however, that burning a very lean fuel/air mixture also reduces NO_x emissions substantially. Because methanol has considerably wider flammability limits than does gasoline, the use of methanol opens new opportunities for controlling NO_x.

[10] J. A. Alic, "Lean-Burning Spark Ignition Engines—An Overview," *Proceedings, 2nd Annual UMR-MEC Conference on Energy,* Rolla, Mo., Oct. 7-9, 1975, p. 143.

Photo credit: Ford Motor Co.

Shown is a fleet of vehicles that run on alternative fuels. The AFV (left front), a two-passenger concept car that runs on compressed natural gas; a four-door Escort (right front), that is fueled by methanol, a Granada (center), that runs on propane; and an Escort (rear), that is powered by ethanol

sufficient quantities of methanol could be produced to consider using it as the only or principal fuel for some automobiles.

If methanol-fueled engines receive intensive development aimed at maximizing fuel economy and driveability, driving-cycle fuel-efficiency improvements (on a Btu basis) of 20 percent or more should be possible, compared with a well-developed but otherwise conventional SI engine burning gasoline. Most of the improvement stems from the higher octane rating of methanol, which would permit compression ratios in the range of 11 or 12:1—perhaps even higher, depending on whether preignition is a serious limiting factor—as well as the somewhat leaner air-fuel ratios possible.

The engineering of vehicles to run on methanol —or other alchohols—is rather straightforward.[11] Indeed, a good deal of experience has already been accumulated. Despite the greater efficiency possible with methanol, vehicles fueled with it probably will require larger fuel tanks to achieve acceptable cruising ranges, because methanol has significantly less energy per gallon than gasoline or diesel fuel. Methanol corrodes some of the materials commonly used in gasoline-fuel systems, which must be replaced by more corrosion-resistant components.

Because alcohols have much higher heats of vaporization than gasoline and therefore do not vaporize as easily, alcohol-fueled engines are more difficult to start in cold weather. Driveability during warmup also tends to be poor. Fuel injection is one approach to mitigating such difficulties. Another solution is to start and warm up the engine on a different fuel. In Brazil, where many cars and trucks run on 100 percent ethanol, engines are typically started on gasoline via an auxiliary fuel system. A lower cost alternative might be to blend in a small fraction—5 to 10 percent—of a hydrocarbon to aid in starting and warmup. Fuel blends could be tailored seasonally just as gasolines are.

Methanol also offers advantages in reducing heat losses and thus raising fuel efficiency. Although its high specific heat and high heat of vaporization can cause starting and warmup problems, these characteristics also mean that the fuel can, in principle, be used to help control internal engine temperatures and heat flows so as to reduce heat losses.

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[11] "CH_3OH: Fuel of the Future?" *Automotive Engineering*, December 1977, p. 48.

Test programs with alcohol fuels have sometimes shown abnormally high engine wear—particularly piston ring and bore wear. While the causes have not yet been fully determined, corrosion, perhaps associated with wall-washing and crankcase dilution during cold-start, are possible contributing factors.[12] If this is the case, solving the cold-start and warmup difficulties would also be expected to cut down on wear. Oil additive packages specially tailored for alcohols should be a further help.

Emissions from methanol-burning automobiles can be controlled with many of the same technologies used for gasoline engines. However, because of the differing fuel chemistries, standards developed for gasoline-burning vehicles are not necessarily appropriate for alcohols. Aldehydes, for example, may need to be controlled.

Battery-Electric and Hybrid Vehicles

The automobile powerplants considered by OTA for increased fuel efficiency are all heat engines—i.e., they convert the energy (heat) produced when a fuel burns into mechanical work. Passenger cars can also be powered from energy stored in forms other than fuel—e.g., by mechanical energy drawn from a spinning flywheel. Among these alternative storage media are rechargeable batteries that convert chemical energy into electrical energy. The electric energy can then drive a direct current (DC) (or sometimes, through an inverter, an alternating current (AC)) motor. Many of the first automobiles built, around the turn of the century, used battery-electric power.

In an extension of the battery-electric concept —called a hybrid—a conventional heat engine drives a generator (or alternator) which can then supply power to an electric motor directly, charge batteries, or both—depending on the instantaneous needs of the driving cycle. A parallel hybrid is designed so the heat engine can also power the wheels directly, through a transmission (the engine turns the generator and the drive wheels in parallel). A series hybrid, in contrast, has no direct mechanical connection between heat engine and drive wheels. Diesel-electric submarines provide examples of both series and parallel hybrid powertrains, but automobiles have never been mass produced with either arrangement.

Whether or not a battery-electric or hybrid automobile would have an overall energy conversion efficiency greater or less than a more conventional SI- or CI-powered car depends on many variables, including the sources of the electricity used to charge the batteries. In the context of this report, the potential of battery-electric or hybrid vehicles as *substitutes* for petroleum-based fuels is more important than the net energy conversion efficiency. If the electricity for charging the batteries comes from a coal or nuclear generating plant—or any other nonpetroleum energy source—widespread sales of such cars could help conserve liquid petroleum.

At present, however, the limitations of practical electric and hybrid vehicles far outweigh any advantages that might be gained from their petroleum-displacing effects.[13] Battery-electric cars will have very limited applications until the performance of batteries (as measured, for example, by the quantity of energy that can be stored per unit of battery weight), increases roughly fivefold—or unless petroleum availability declines much more rapidly than now expected. Hybrids share many of the disadvantages of battery-electric cars and—although they offer theoretically promising energy conversion efficiencies—are dependent on fuels. Their current prospects are even dimmer than for battery-electrics, in large part because hybrid vehicles would be expensive and complex—the duplication in the powertrain is a formidable cost barrier.

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[12] T. W. Ryan, III, D. W. Naegeli, E. C. Owens, H. W. Marbach, and J. G. Barbee, "The Mechanism Lending to Increased Cylinder Bore and Ring Wear in Methanol-Fueled S.I. Engines," Society of Automotive Engineers Paper 811200, 1981.

[13] R. L. Graves, C. D. West, and E. C. Fox, "The Electric Car—Is It Still the Vehicle of the Future," Oak Ridge National Laboratory Report ORNL/TM-7904, August 1981.

Despite the widespread publicity given to battery-electric automobiles over the past 20 years—most recently, the attention garnered by General Motors' announcement of production plans for the mid-1980's—progress in EVs remains severely limited by battery performance. This is true both for battery systems that are available now and for those that appear to have possibilities for near-term production. Power and energy densities of available batteries remain too low for practical use in other than highly specialized automotive applications. Power density (watt per pound or W/lb) measures the *rate* at which the battery can supply energy. Energy density (watt hours per pound or Whr/lb) measures the *total amount* of energy that can be stored and then withdrawn from the battery. For some battery systems, to get all the energy out requires a slow rate of withdrawal, limiting the instantaneous delivery of power. Because of the transient demands of automotive driving cycles, power density is almost as important for vehicle applications as energy density, which determines the operating range before the batteries need to be recharged.

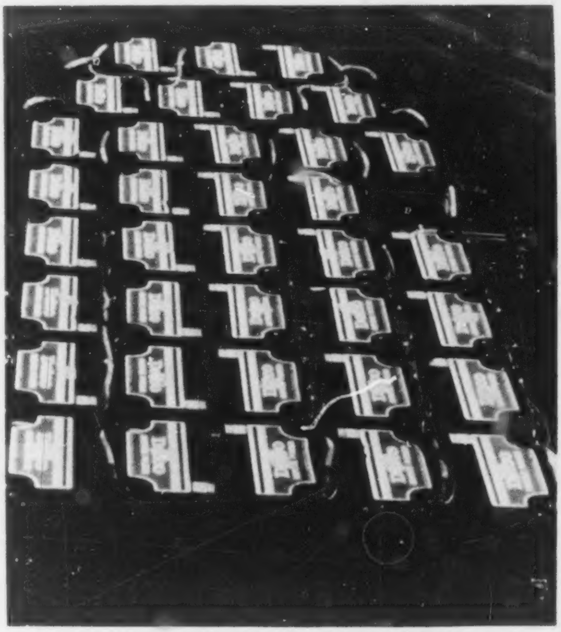
Photo credit: Electric Vehicle Council

A view of the battery-pack configuration in a demonstration electric vehicle

In general, battery systems that are near-term candidates for automotive applications suffer from both low power density *and* low energy density. Table 20, which includes several batteries that are still in rather early stages of development, gives typical values. Energy and power density tend to be inversely related, a particular problem for the familiar lead-acid battery; the inverse relation means that—for any given battery system—the designer can choose higher energy density only at the sacrifice of power density. Limited power density restricts the acceleration capabilities of current EVs to low levels—for some driving conditions, to the detriment of safety. The energy density, in contrast, limits the total amount of energy that can be carried, therefore, the range of the vehicle before the batteries must be recharged. Recharging is a time-consuming process—as much as 10 hours for some, though not all, batteries. If power density and energy density are low, then the vehicle must carry more batteries. This makes it heavier, increasing the demands for power and energy and compounding the design problems.

As a rule-of-thumb, and assuming reasonable costs, an energy density in the vicinity of 100

Table 20.—Potential Battery Systems for Electric (and Hybrid) Vehicles

Battery	Energy density (Whr/lb)	Power density (W/lb)	Status
Lead-acid	15-20	5-20	Available
Nickel-zinc	30-40	40-80	Available, but expensive
Zinc-chlorine	~35	~55	Experimental; potentially inexpensive
Aluminum-air	100-200	~80	Experimental; cannot be electrically recharged (requires periodic additions of water and aluminum)
Sodium-sulfur.	~100	~100	Prospective; high-temperature; potentially inexpensive

SOURCE: Office of Technology Assessment.

Whr/lb, along with a power density of about 100 W/lb, would suffice for a practical general-purpose vehicle. With these characteristics, 400 lb of batteries would give about 100 miles of travel between battery rechargings and produce about 55 horsepower. Urban or commuter cars might get by with somewhat lower figures. Table 20 shows that currently available battery systems either cannot achieve such figures, or—as with nickel-zinc batteries—are too expensive for widespread use.

Battery-electric cars—often production vehicles converted by replacing the engine and fuel system with an electric motor and lead-acid batteries (like the storage batteries used in golf carts)—have been built in prototype or limited-production form for years. At present, a four-passenger electric car with lead-acid batteries would weigh about twice as much as a conventionally powered car, cost twice as much, and have a range of less than 50 miles before recharging. *The battery pack alone would weigh 1,000 lb or more,* and would have to be replaced several times during the life of the vehicle, adding to the operating costs.

In addition to the nickel-zinc batteries mentioned above, there are a number of other candidate battery systems for EVs—of which table 20 includes three as examples—the zinc-chlorine, aluminum-air, and sodium-sulfur batteries. These share the advantage of relatively inexpensive raw materials, but have other drawbacks: for example, the zinc- chlorine battery has low energy density; the aluminum-air system is "recharged," not by an inward flow of electricity, but by mechanical replacement of materials (in consuming materials to produce electricity the aluminum-air battery is like a fuel cell, but fuel cells are continuous-flow devices); the sodium-sulfur battery operates at temperatures greater than 500° F. All of these batteries are experimental, and none has been developed as rapidly as once hoped; the same is true of many other candidate battery systems with theoretically attractive characteristics for EVs and/or hybrid vehicles.[14]

Not only are battery-electric cars severely limited in range and performance by the energy and power densities of available batteries, but production costs would also be high, at least initially. A further and serious disadvantage is the limited life of many prospective battery systems. Often, the batteries would need to be replaced—at high cost—before the rest of the vehicle reached the end of its useful life. Battery-electric cars also pose new and different safety problems, such as spills of corrosive chemicals in the event of an accident.

Battery-electric powertrains may have a place in local delivery trucks, and perhaps for small, specialized commuter cars. More widespread use depends on large improvements (a factor of at least 5 in battery performance, particularly energy density). Although research and development (R&D) on battery systems for EV applications will continue, there seems little likelihood of significant production—i.e., hundreds of thousands of vehicles per year—before the end of the century. "Breakthroughs" in batteries are improbable; slow incremental progress is more likely to characterize R&D on battery systems, and hence EV (and hybrid) vehicles. Moreover, by the time battery performance is improved sufficiently for practical application, progress in fuel-cell technology may make the latter a more attractive option. (Fuel cells convert a fuel, now generally hydrogen but potentially a hydrocarbon or methanol, directly to electricity.)

Hybrids also are limited by battery performance, but the onboard charging capacity means that not as many batteries are needed, so the battery pack is lighter. However, hybrids must carry a complete heat engine, as well as a generator or alternator, and an electric drive motor. Although the engine can be small, because it need not be capable of powering the vehicle by itself, the cost and complication of the hybrid powertrain are prohibitive, at least at present. The complication comes not only from the duplicate energy conversion and drive systems but also from the control system. While the performance requirements for the control system are not unusual, the need for a reliable, mass-produced system at reasonable cost does create a demanding set of constraints. The added weight of the batteries and duplicate drivetrain, and the efficiency losses associated with recharging the batteries, also tend to counteract the theoretical advantages of hybrids in fuel economy.

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[14] A. R. Landgrebe, et al., "Status of New Electrochemical Storage and Conversion Technologies for Vehicle Applications," *Proceedings of the 16th Intersociety Energy Conversion Engineering Conference,* Atlanta, Ga., Aug. 9-14, 1981, Vol. 1 (New York: American Society of Mechanical Engineers, 1981), p. 738.

FUTURE AUTOMOBILE FUEL EFFICIENCY

Automobile technology is not a major constraint on fuel economy. Small cars can be designed today—indeed, are on the market—with mileage ratings twice the current new-car average. Technology *is* important for increasing the fuel economy of the larger, more powerful, and more luxurious cars that many Americans still desire. Evolutionary improvements will continue to increase the mileage of both large and small cars, but the pacing factor at the moment is market demand.

Because consumer demand is unpredictable, estimates of post-1985 fuel economy are uncertain; these estimates largely reflect expectations of the importance consumers will place on size and gas mileage. Projections of the fuel economy that the U.S. new-car fleet will achieve vary widely, but most now tend to be optimistic. Only 2 or 3 years ago, American automakers viewed the CAFE standards, correctly, as pushing their product lines away from the sorts of cars that most consumers still demanded. Now many of those same consumers are buying cars with average fuel economies above the CAFE requirements.

EPA statistics indicate that average domestic new-car fuel economy averaged almost 24 mpg for 1981 models sold through January 5, 1981.[15] If imports are included, the figure is about 25 mpg. A few predictions are as high as 90 mpg for 1995 or 2000, although such projections are usually exhortations rather than realistic attempts to project future trends. While the technology to achieve such efficiencies will exist, fleet averages are likely to remain well below the economy ratings that the best performers will be able to achieve.

The primary differences among the many projections of automobile fuel economy for the years ahead arise from varying assumptions of future market demand. Different assumptions for the rate of introduction of new technology are also common. A constraint for American manufacturers may be the ability to generate and attract capital for R&D and for investment in new plant and equipment, particularly if movement toward small, high-mileage cars and introductions of new technology are more rapid than domestic firms have been anticipating. Many foreign automakers already produce cars that are smaller and lighter —and get better fuel economy—than those they now sell in the United States.

Although the fuel economy achieved by the new-car fleet in future years will depend strongly on market demand and the health of the auto industry, technology is also important. Both the timing of new vehicle designs and their ultimate costs—whether routine downsizing and materials substitution, or more demanding tasks such as improved powerplants—depend on extensive programs of engineering development. These take time and talent, as well as money. Complete success can never be guaranteed. Some projects will have more satisfactory outcomes than others.

To distinguish these technological dimensions from questions of market demand, the discussion below first outlines two scenarios for future developments in automobile technology. Designated the "high-estimate scenario" and the "low-estimate scenario," they represent plausible upper and lower bounds for fleet average passenger-car fuel economy in future years. Of course, among the cars on the market in any year, some would have mileage ratings considerably below, some considerably above, the fleet averages for that year. These scenarios are independent of market demand for cars of various size classes, and are simply based, respectively, on optimistic and pessimistic expectations for rates of advance in automobile technology as these affect fuel economy. Using these scenarios, later sections of the chapter discuss the effect of market demand on the fuel economy of the U.S. auto fleet.

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[15] "Light Duty Automotive Fuel Economy . . . Trends Through 1981," op. cit.

Technology Scenarios

Both the high- and low-estimate technology scenarios take as a baseline the new-car fuel economy now expected for 1985. This baseline includes a number of technical advances, as well as further downsizing, compared with 1982 model cars. While the product plans of individual manufacturers for 1985 are not known in detail, the broad outlines of 1985 passenger-car technologies can be easily discerned. The scenarios then cover the period 1985-2000. The *high estimate* assumes:

- that engineering development projects aimed at improving fuel economy are generally successful;
- that these technological improvements are quickly introduced into volume production; and
- that they produce fuel economy improvements at the high end of the range that can now be anticipated.

The *low estimate* assumes, in contrast:

- that development projects are not as successful—e.g., that technical problems decrease the magnitude of fuel-economy gains, lengthen development schedules, and/or result in high production costs;
- the pace of development is slower than would result from the vigorous efforts to "push" automotive technology assumed for the high estimate scenario; and
- the resulting fuel-economy improvements are at the low end of the range that can now be anticipated.

From a technological perspective, the vehicle subsystem most critical for fuel-economy improvements is the powertrain—i.e., the engine and transmission. Here, as in other aspects of automotive technology, more-or-less continuous evolutionary development can be expected. But major changes in powertrains have also been occurring—e.g., new applications of diesel engines to passenger cars.

The pace of development may vary for other aspects of automobile technology—aerodynamics, downsizing and weight reduction, power consumption by accessories—but individual innovations with large impacts on fuel economy are unlikely. Engine developments, in contrast, depend more heavily on successful long-term R&D programs; fundamental knowledge—e.g., of combustion processes—is often lacking, and the risks as well as the rewards can be large. In contrast, development programs aimed, for instance, at friction reduction, are likely to be more straightforward—and less costly.

Table 21 presents OTA's high and low estimates for improvements in fuel economy by category of technology, based largely on informed technical judgments.* Relative to an assumed 1985 car which gets 30 mpg (EPA rating, 55 percent city, 45 percent highway driving cycle), table 21 indicates that gains of 35 percent in fuel economy may be possible from engine redesigns, but that percentage improvements in transmissions and vehicle systems are likely to be smaller. Nonetheless, the cumulative improvements in fuel economy can be quite large.

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*Alternative methodologies for estimating future fuel economy—e.g., the use of learning curves, or analytical modeling of the vehicle system—generally lead to comparable results. All approaches to projecting fuel economy have their limitations. The method adopted by OTA does not always do the best job of evaluating the systems effects of combining different technologies—i.e., open-chamber diesel engines combined with four-speed lockup torque converters. Learning curves, based on historical trends, do not take explicit account of new technologies. Analytical modeling is a valuable tool for comparing alternative technologies, but models must be validated by comparison with hardware results before the model can be used with confidence.

Table 21.—Prospective Automobile Fuel-Efficiency Increases, 1986-2000

	Percentage gain in fuel efficiency[a]					
	High estimate			Low estimate		
Technology	1986-90	1991-95	1996-2000	1986-90	1991-95	1996-2000
Engines						
Spark-ignition (SI)	10	10-15	15	5	5-10	5-10
Diesel:						
Prechamber	15	15		15	15	
Open chamber	25	35	35	20	20	25
Open chamber (SI) stratified charge (SC)		15	20			
Hybrid diesel/SC			35			
Transmissions						
Automatic with lockup torque converter	5	5	5	5	5	5
Continuously variable (CVT)		10	15			10
Engine on-off		10	10			10
Vehicle system						
Weight reduction (downsizing and materials substitution)	8	13	18	4	8	10
Resistance and friction (excluding engine)						
Aerodynamics	2	3	4	1	2	3
Rolling resistance and lubricants	1	2	3	1	1	2
Accessories	2	3	4	1	1	2

[a] Improvements in fuel efficiency are expressed as percentage gain in mpg compared with an anticipated average 1985 passenger car. The 1985 average car used as a reference has an inertia weight of about 2,500 lb, is equipped with spark-ignition engine, three-speed automatic transmission, and radial tires, and has an EPA mileage rating (55 percent city, 45 percent highway) of 30 mpg. The fuel efficiencies of the individual baseline cars, which are used to calculate future fuel efficiencies in each size class, are given in tables 23 and 24. Percentages are given on an equivalent Btu basis where appropriate—e.g., for diesels, which use fuel having higher energy content per gallon than gasoline, the percentage gain refers to miles per gallon of gasoline equivalent, which is 10 percent less than miles per gallon of diesel fuel. The table does not include efficiency improvements from alternate fuels such as alcohol.

SOURCE: Office of Technology Assessment.

None of the figures in this table should be interpreted as predictions. Rather, they illustrate ranges in fuel-economy improvement, based on OTA's judgment of what is likely to be technically practical. The projected improvements are not directly associated with the developmental programs of specific automobile manufacturers—either domestic or foreign. As changes in automobile technology occur, older designs will coexist with new—just as, recently, older V-8 SI engines have remained in production alongside replacements such as diesels and V-6 SI engines. New engines and transmissions are typically introduced with the presumption that they will remain in production for at least 10 years. These rather slow and gradual patterns of technological change are likely to continue unless market conditions force an acceleration. For this to happen, the market pressures would have to be rather intense, if only because of the limited capital resources available at present to the domestic automakers.

Table 21 lists the net improvements in automobile components that could be expected, on the average, for the high and low estimates during each 5-year period. Note that the technologies listed in the table are not in every case compatible with one another, nor can any simple combining procedure yield net figures that have clear and direct meaning for particular hypothetical vehicles. This is because different technologies combine in different ways. For example, the poor part-load efficiencies of throttled SI engines mean that continuously variable transmissions and engine on-off will yield greater improvements than for partially throttled open-chamber stratified-charge engines or diesels. Thus, the choice of cost-effective technologies cannot be inferred from such a table alone, but must depend on more detailed analysis, and finally on testing.

The technologies listed in table 21 are discussed in more detail in appendix 5A at the end of this chapter.

Projection of Automobile Fleet Fuel Efficiency

Based on the technological scenarios in table 21 and several assumptions about the size mix of new cars, OTA has constructed a set of projections for the fuel economy of passenger cars sold in the U.S. market in future years. As emphasized earlier in this chapter, market demand—not technology—is the key factor in determining the mileage potential of the new-car fleet. Market demand is particularly critical in determining the size mix of new-car sales.

The automobile technologies listed in table 21 are more important as tools for increasing the fuel economy of the larger, more luxurious cars that many American purchasers still demand than for cars that are small and light—e.g., nearly all current imports, as well as the new generations of American-made subcompacts. Improved powertrains and the use of materials with high strength-to-weight ratios will lead to improved fuel economy in cars of all sizes. But a 10-percent increase in gas mileage for a big car—with mileage that is initially low—saves more fuel than a 10-percent improvement to a small car that is already more fuel efficient.

This is not to say, however, that a given technological development will necessarily give the same percentage improvement for cars of all sizes—or even be applicable to all types of cars. Continuously variable transmissions (CVTs) have been in limited use for many years in small cars, and would no doubt be applied widely in subcompacts before finding their way into heavier vehicles. The reason is simply that the mechanical design problems for a CVT are simpler if the levels of torque that must be transmitted are low.

On the other hand, if gas turbines become practical as automobile powerplants, they are likely to be used first—and perhaps exclusively—in big cars, because turbine engines are more efficient in larger sizes.

Any projection of fleet fuel economy will depend on the assumed weight (size) mix of new-car sales in the years ahead. For its analysis, OTA adopted a simplified description of this mix, based on three size classes—small, medium, and large. This allows possible market shifts to be analyzed in terms of the assumed proportion of new-car sales by size class—for each of which the *average* fuel economy has been estimated. This is a considerable abstraction from the real situation—one in which the spectrum of curb weights from which consumers select extends from less than 2,000 lb to over 4,000 lb. For any given weight—now and in the future—there will also be a range of fuel economies, depending on vehicle design. The convenience of the description in terms of only three size classes, for which other characteristics are averaged, comes at the expense of the richness and variety that will actually exist in the marketplace.

New-Car Fuel Efficiency by Size Class

Table 22 describes the small, medium, and large size classes on which OTA's projections are based. The scheme is similar to current EPA practice for fuel-economy ratings—grouping cars of similar passenger capacity and interior volume. However, the designations of car sizes in table 22 differ from some current designations because they are intended to reflect future vehicle characteristics rather than the past; in other words, OTA prefers to call a future small car just that, not a "minicompact." Each class in the table encompasses a considerable range of possible vehicle designs. Under either the high or low estimate scenarios, curb weights of cars in the U.S. fleet are expected to decrease over the period 1985-2000.

Table 22.—Small, Medium, and Large Size Classes Assumed for 1985-2000

	Curb weight[a] (lb)				1981 equivalents	
Class	High estimate	Low estimate	Interior volume (ft³)	Passenger capacity	Size class	Typical models
Small	1,300-1,600	1,400-1,700	<85	2-4	Minicompact, two seaters	Honda Civic Toyota Starlet
Medium	1,600-2,000	1,700-2,000	80-110	4	Subcompact, compact	VW Rabbit Chrysler K-Car
Large	2,200-3,000	2,500-3,000	100-160	5-6	Intermediate, large, luxury	GM X-Car Ford Fairmont

[a] Curb weight is the weight of the car without passengers or cargo.

SOURCE: Office of Technology Assessment.

Tables 23 and 24 expand on the descriptions in table 22. For these tables, OTA has estimated weight averages, engine alternatives, and average fuel economies at 5-year intervals through 2000 for the two technology scenarios. Again, these estimates reflect informed technical judgment but should not be viewed as predictions. The curb weights are averages expected for each of the three size classes; rather broad ranges in actual weights are likely, especially in the medium and large classes. The fuel economy estimates are likewise averages with considerable spread anticipated. Fuel economy projections are given in terms of current EPA rating practice (combined city-highway figures)—which overestimate actual over-the-road mileage by as much as 20 percent. The EPA rating basis has been adopted for ease of comparison with fuel economy ratings for the current fleet; in later sections, to estimate actual fuel consumed, EPA ratings are adjusted downward to more realistic values.

The average fuel economy estimates in tables 23 and 24 for the high- and low-estimate technology scenarios are grouped together in table 25 so that the differences by size class and technology level can be more easily compared. Table 25 illustrates the importance of size and weight for fuel economy. By 2000, the low-estimate average efficiency for medium-size cars is the same as the high-estimate efficiency for big cars—both are 50 mpg. Large cars show the greatest percentage improvements because more can be done to improve fuel economy before diminishing returns become severe.

One way to abstract the effects of downsizing and weight reduction from other technological improvements is to examine specific fuel economy—by normalizing to ton-mpg, or the miles per gallon that would result for an otherwise similar car weighing 1 ton. Ton-mpg values have exhibited an upward trend over time as automotive technologies have improved.[16]

Figure 9 shows the gradual increase—with considerable year-to-year fluctuations—that has characterized average fuel economy in ton-mpg for the U.S. new-car fleet over the past decade, together with estimates through 2000 based on the

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[16] "Powerplant Efficiency Projected Via Learning Curves," *Automotive Engineering*, July 1979, p. 52.

Table 23.—Automobile Characteristics—High-Estimate Scenario

	Small				Medium				Large			
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Average curb weight (lb)	1,600	1,500	1,400	1,300	2,000	1,800	1,700	1,600	3,000	2,600	2,400	2,200
Engine type (percent):												
Spark ignition	100	95	70	60	90	70	50	30	75	30	30	25
Prechamber diesel	—	5	—	—	10	10	—	—	25	40	—	—
Open chamber diesel or open chamber stratified charge	—	—	30	40	—	20	50	70	—	30	70	75
Fuel economy[a] (mpg)	48	62	74	84	39	51	61	71	27	37	43	49

[a] Combined EPA city/highway fuel-economy rating, based on 55 percent city and 45 percent highway driving.

SOURCE: Office of Technology Assessment.

Table 24.—Automobile Characteristics—Low-Estimate Scenario

	Small				Medium				Large			
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Average curb weight (lb)	1,700	1,600	1,500	1,400	2,000	1,900	1,800	1,700	3,000	2,800	2,600	2,500
Engine type (percent):												
Spark ignition	100	100	100	60	90	80	70	70	75	60	50	40
Prechamber diesel	—	—	—	—	10	20	30	—	25	40	20	—
Open chamber diesel	—	—	—	40	—	—	—	30	—	—	30	60
Fuel economy[a] (mpg)	45	52	57	65	35	41	45	50	23	28	31	34

[a] Combined EPA city/highway fuel-economy rating, based on 55 percent city and 45 percent highway driving.

SOURCE: Office of Technology Assessment.

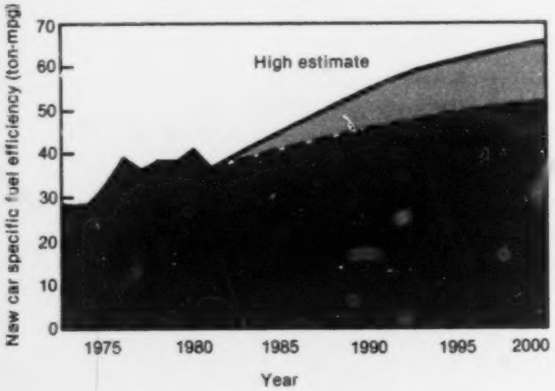
Table 25.—Estimated New-Car Fuel Economy: 1985-2000

Size class	Average new-car fuel economy[a]			
	1985	1990	1995	2000
Large:				
High estimate	27	37	43	49
Low estimate	23	28	31	34
Medium:				
High estimate	39	51	61	71
Low estimate	35	41	45	50
Small:				
High estimate	48	62	74	84
Low estimate	45	52	57	65

[a] Combined EPA city/highway fuel-economy rating, based on 55 percent city and 45 percent highway driving.

SOURCE: Office of Technology Assessment.

Figure 9.—Sales-Weighted Average New-Car Fleet Specific Fuel Efficiency



SOURCE: Office of Technology Assessment.

high and low scenarios in table 21. As for the earlier tables, figure 9 aggregates both domestic automobiles and imports. Using such projections, the fuel economies of future new-car fleets of various size (weight) mixes can be estimated.

As the figure shows, average specific fuel consumption for new cars sold in the United States has increased from less than 30 ton-mpg in the early 1970's to roughly 39 ton-mpg in 1981, a 30-percent improvement. The most efficient 1981 cars sold in this country gets 50 ton-mpg.* By 1990, the average should equal the current best. By 2000, the *average* could be as high as 65 ton-mpg.

Based on the projections in tables 23-25, or alternatively those in figure 9, the effects of changes in the size mix of the new-car fleet can be estimated. In the mix of new 1981 cars sold through January 5, 1981, small cars made up only 5 percent of the market; the rest was almost evenly divided between medium cars (48 percent) and large cars (47 percent). By 1985, the share of small cars may remain at 5 percent, but the share of medium cars is expected to go up at least to 60 percent, dropping the large-car share to 35 percent or less. Even in the unlikely event that the 60:35 ratio remains unchanged beyond 1985—that medium cars show no further sales gains over large cars—the average fuel economy of the new-car fleet in 2000 would be 62 mpg in the high-estimate scenario, 43 mpg in the low-estimate scenario.* (See table 26, "no mix shift" case.) These figures represent a substantial improvement over the 25 mpg expected in 1981 and the 30 to 35 mpg expected for 1985. A further shift in consumer preference toward smaller and lighter cars would increase the expected fleet-average fuel economy even more.

To illustrate the effects of a continuing shift towards smaller and lighter cars, table 26 also gives average fuel economies at 5-year intervals for a "moderate" mix shift—leading to 35 percent small cars, 50 percent medium cars, and 15 percent large cars by 2000—and for a "large-scale" mix shift. The latter assumes 70 percent small cars, 25 percent medium cars, and only 5 percent large cars in 2000. As the table shows, the large-scale mix shift could give a new-car fleet average fuel economy of 60 to 80 mpg by 2000. Whether market demand will lead to such a mix shift depends on factors such as price differentials between large and small cars, and the compromises in other vehicle characteristics that accompany smaller cars, as well as the pricing and availability of fuel.

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*These are diesels, for which the ton-mpg rating has been expressed on a gasoline-equivalent basis; the value based on diesel fuel would be about 55 ton-mpg. The best current SI engine models sold in the United States have ton-mpg ratings about 10 percent lower, or roughly 45 ton-mpg.

*The corresponding numbers for the 1981 mix are 59 mpg in the high estimate and 41 mpg in the low estimate.

Table 26.—Effect on Size Mix on Estimated Fuel Economy of the New-Car Sales in the United States

	Estimated average new-car fuel economy[a] (mpg)											
	No mix shift[b]				Moderate mix shift[c]				Large-scale mix shift[d]			
Technology scenario	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
High estimate	34	45	54	62	34	48	59	70	37	53	65	78
Low estimate	30	36	39	43	30	38	43	51	33	43	49	58

[a] 55 percent city, 45 percent highway EPA rating.

[b] The no mix shift case assumes:

Size class	Sales mix (percent) for all years
Small	5
Medium	60
Large	35

[c] The moderate mix shift assumption is as follows:

	Sales mix (percent)			
Size class	1985	1990	1995	2000
Small	5	15	25	35
Medium	60	60	55	50
Large	35	25	20	15

[d] The large-scale mix shift assumption is:

	Sales mix (percent)			
Size class	1985	1990	1995	2000
Small	10	30	50	70
Medium	75	65	45	25
Large	15	5	5	5

SOURCE: Office of Technology Assessment.

ESTIMATED FUEL CONSUMPTION, 1985—2000

In this section estimates of the fuel consumed by the U.S. passenger-car fleet are based on the various assumptions and projections of car size mix and efficiency discussed above, but assume that gasoline and diesel fuel continue to power passenger vehicles, with no significant penetration of alternative fuels such as methanol.

In 1975, when Federal fuel economy standards were enacted, passenger cars consumed an average of about 4.3 MMB/D of fuel. (Trucks are omitted from the calculations in this chapter, but many light trucks and vans are used interchangeably with passenger cars and add about 1.1 MMB/D to average consumption). Passenger-car fuel consumption rose to 4.8 MMB/D in 1978, but has since declined to 4.3 MMB/D—about the 1975 level.[17] OTA projects that passenger-car fuel consumption will continue to decline—to about 3.6 MMB/D in 1985, as the automobile fleet becomes more fuel-efficient. This estimate assumes that the fleet will grow from about 107 million cars in 1980 to 110 million in 1985, and that the average car will continue to accumulate about 10,000 miles per year.

Projected Passenger-Car Fuel Consumption

The baseline chosen for discussing fuel consumption by passenger cars past 1985 is outlined in table 27. Growth in the automobile fleet—which depends on both sales levels for new cars, and the rates at which older cars are scrapped—is

Table 27.—Baseline Assumptions for Projections of Automobile Fuel Consumption

	1980	1985	1990	1995	2000	2005	2010
Vehicle miles of travel:							
Trillion miles/yr	1.14	1.17	1.20	1.23	1.26	1.28	1.31

Also assumes 47 percent of fleet vehicle miles traveled (VMT) by cars less than 5 years old, 38 percent of VMT by cars 5 to 10 years old, and 15 percent of VMT by cars older than 10 years.

New-car fuel economy (combined EPA ratings; 55 percent city, 45 percent highway):

1985 base case (low-high estimate)

Small cars:	45-48 mpg
Medium cars:	35-39 mpg
Large cars:	23-27 mpg

Fleet baseline average efficiency
30 mpg, 1985-2010

High- and low-estimate scenarios
See table 25

On-the-road fuel efficiency:
10 percent less than EPA rated fuel efficiency

Size mix:
See table 26

SOURCE: Office of Technology Assessment.

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[17] Derived from J. K. Pollard, et al., "Transportation Energy Outlook: 1985-2000," Transportation Systems Center, U.S. Department of Transportation, DOT-TSC-RS-112-55-81-6, September 1981, pp. 4-21; and "Monthly Energy Review," Energy Information Agency, U.S. Department of Energy, DOE/EIA-0035 (81/10), October 1981.

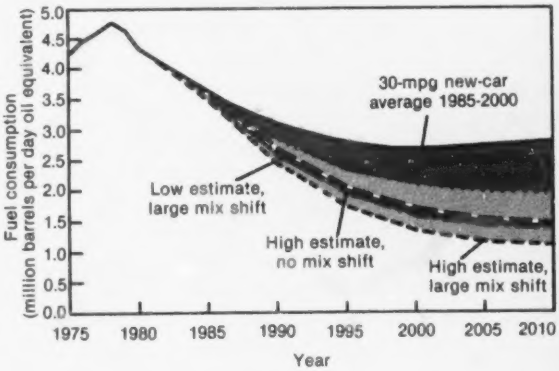
projected to average less than 2 percent per year.[18] Cars are assumed to be driven an average of 10,000 miles per year, with newer cars driven more and older cars driven less, on the average (see table 27). The projections for new-car fuel economy and future size mix are taken from the tables in earlier sections. Because those fuel-economy projections were based on EPA ratings, which overestimate actual on-the-road mileage, fuel economy has been adjusted downward 10 percent to compensate.

If *neither* fuel economy nor size mix were to advance past a 1985 baseline average of 30 mpg, fuel consumption by passenger cars would still decline slowly for 10 years, reflecting the larger fraction of cars in the fleet with fuel economies at this baseline value. Between 1985 and 1995, passenger-car fuel consumption would decline—even with a status quo in fuel economy and size mix—from about 3.6 MMB/D in 1985 to 2.7 MMB/D in 1995. Thereafter, the upward trend would resume because of increases in the total size of the fleet.

But of course, automobile technology will continue to improve (table 21), and a continuing shift toward smaller cars is also probable (table 26). Therefore, under almost any realistic set of assumptions, passenger-car fuel consumption will continue to decrease during the post-1995 period. At some point it may still turn upward because of increases in fleet size, this turning point depending on both technology and size mix. In any case, as figure 10 shows, the decline in passenger-car fuel consumption will level off by about 2005 (unless growth in the fleet is slower than projected in table 27 or cars are driven fewer miles per year).

Figure 10 gives fuel-consumption projections to 2010 based on these assumptions. The influence of technological improvements is striking. For example, even without a mix shift toward cars smaller than in the 1985 baseline mix, the high estimate gives fuel savings greater than those for the low estimate *with* a large-scale shift towards smaller cars. But such a mix shift would also create substantial fuel savings. For the cases plotted in this figure, passenger-car fuel consumption stays well below 2.5 MMB/D during the early years of the next century. The figure also shows the potential benefits if technical success is accompanied by a strong shift to smaller cars. The difference in 2010 between the low estimate with no mix shift (about 2.0 MMB/D), and the high estimate with a large mix shift toward smaller cars (1.1 MMB/D), is nearly a factor of 2. The lower end of this range is about one-fourth the current level of fuel consumption. *Where* within this range the actual fuel consumption would fall is likely to depend—as emphasized earlier—on market demand for fuel-efficient vehicles, and/or continuing Government policies designed to encourage the manufacture and purchase* of fuel-efficient cars. Changes in vehicle miles traveled would also change the fuel consumption proportionately.

Figure 10.—Projected Passenger-Car Fuel Consumption



SOURCE: Office of Technology Assessment.

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[18] *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 140-141.

*An illustration of the importance of new-car sales can be derived as follows: In 1980, 47 percent of the vehicle-miles traveled (VMT) were by cars 0 to 4 years old, 38 percent by 5 to 9 year old cars, and 15 percent by cars 10 years old and older. Call this the base case. A persistent 20 percent depression in new car sales could change the VMT distribution by 1995 to: 40 percent by cars 0 to 4 years old, 35 percent by cars 5 to 9 years old. and 25 percent by cars 10 years old and older. Call this the "low" car sales case. If VMT are held constant at the 1980 level, fuel consumption under the base case would be up to 0.3 MMB/D (or nearly 20 percent) *lower* than fuel consumption in the "low" car sales case in 1990, everything else being equal. And cumulative oil savings could be over 1 billion bbl during the period 1981-2000. The base case, however, probably would be accompanied by higher VMT than the "low" sales case, and much of this savings could be lost.

Total projected oil savings are bracketed by the curves in figure 11. These show the fuel conserved relative to the 1985 baseline case of new-car efficiencies of 30 mpg between 1985 and 2010. Clearly, the high-estimate technology scenario, accompanied by a continuing shift toward smaller cars, leads to large fuel savings. By 2010—when virtually the full benefit of fuel savings from cars sold in the period 1985-2000 would be realized—the cumulative savings (relative to a 30-mpg fleet) could be as high as 10 billion bbl of oil equivalent. This is equivalent to 6 years supply of passenger-car fuel at the 1980 rate of consumption. The fuel economy increases expected between now and 1985 would add about 14 billion bbl to this cumulative savings between now and 2010 (relative to 1980 fuel consumption). Thus, between now and 2010, the total savings possible is about 24 billion bbl relative to 1980 passenger-car fuel consumption—an amount about equal to proven U.S. oil reserves, which were 26.5 billion bbl as of 1980.[19]

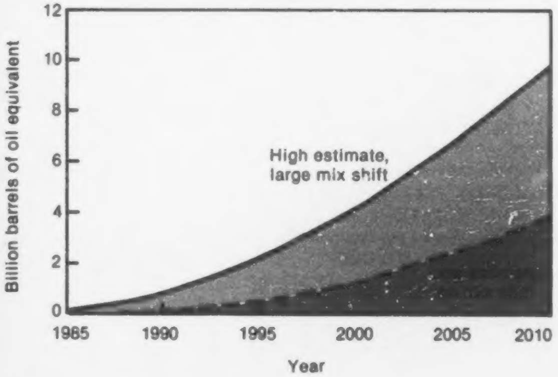
Substitution of Electric Vehicles

The estimates above are based on a passenger-car fleet for which energy comes from a fuel carried onboard—e.g., gasoline or diesel fuel. In the "Battery-Electric and Hybrid Vehicles" section, the prospects for EVs were briefly discussed, with the conclusion that major improvements in battery performance were necessary before EVs (or hybrids) would be practical in any but very specialized applications. If, however, these improvements are achieved—or if acute shortages of transportation fuels occur in the future—EVs might be sold in sufficiently large numbers to affect petroleum consumption.

The result would be to replace some of the petroleum consumed in the transportation sector by electric power generation. To the extent that this electricity was produced from nonpetroleum fuels—e.g., natural gas, coal, nuclear—the cumulative oil savings shown in figure 10 would increase (see app. 5B). Table 28 illustrates the results for a highly optimistic level of EV substitution. Note that this again is *not* a prediction; substantial penetration by electric and/or hybrid vehicles (EHVs) before the end of the century is unlikely, and doubtful even thereafter. The table simply shows what might happen *if* battery improvements occur more rapidly than OTA expects, or if other factors combine to increase the attractiveness of EHVs. Table 28 assumes that EHVs represent 5 percent of the total U.S. passenger-car fleet by 2000, and 20 percent by 2010. This would require EHV production and sales at levels of several million per year during the last few years of the century.

Table 28 shows that penetration of EHVs at high enough rates could begin to replace meaningful volumes (14 percent) of transportation fuels dur-

Figure 11.—Cumulative Oil Savings From Increased Automobile Fuel Efficiency Relative to 30 MPG in 1985, No Change Thereafter



SOURCE: Office of Technology Assessment.

Table 28.—Effects of Substituting Electric Vehicles[a]

	Composition of passenger-car fleet (million)		Passenger-car fuel consumed or replaced (MMB/D)	
	2000	2010	2000	2010
Conventional cars	133	124	1.7	1.4
EVs	7	31	0.04	0.2
Percent EVs	5	20	—	—
Percent fuel consumption replaced	—	—	2	14

[a] If battery improvements occur more rapidly than OTA expects, or if other factors combine to increase the attractiveness of electric vehicles.

SOURCE: Office of Technology Assessment.

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[19] *World Petroleum Availability 1980-2000—Technical Memorandum,* OTA-TM-5 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1980.)

ing the first decade of the next century. Nonetheless, the savings in petroleum would be relatively small in absolute terms—because EHVs are best suited as replacements for small cars which already get good mileage.

Comparing the estimated fuel savings in table 28—only 0.2 MMB/D even for optimistic assumptions of EHV penetration—with the fuel-consumption trends projected in figure 9, demonstrates that improvements in automobile technology, particularly if combined with more rapid mix shifts toward smaller cars, offer much greater potential. Thus, the primary apparent advantage of EVs during the next 30 years is that they would not depend on petroleum supplies—an important factor if severe absolute shortages develop—rather than any potential for *saving* petroleum.

Fuel Use by Other Transportation Modes

Thus far, the discussion of fuel consumption has been restricted to passenger cars, although, as pointed out earlier, many light trucks—i.e., vans and pickups—are used primarily for passenger travel. In addition, medium and heavy trucks, buses, motorcycles, and airplanes—plus rail and marine transportation and military operations—consume petroleum-based fuels. All of these transportation modes depend predominately on heat engines for power, although SI engines are not so widely used as in passenger cars. Diesels have already replaced SI engines in almost all heavy trucks, and rates of installation in medium-duty trucks are going up rapidly. Diesels are also common in rail and marine applications, although some large ships rely on gas turbines or steam power. Commercial aircraft are generally powered by turbine engines.

Table 29 summarizes the projected oil consumption for transportation between 1980 and 2000. The projections for automobiles are derived in this chapter, while those for other transportation modes are taken from the "market trend" base case in a recent Department of Transportation study.[20] The projections for fuel consumption by trucks in table 29 assume that many of the technological improvements discussed above for passenger cars will also be applicable to light trucks. However, the specific technologies discussed elsewhere in this chapter are more generally appropriate to pickup trucks and vans than to medium and heavy trucks.

Table 29.—Projected Petroleum-Based Fuel Use for Transportation

	1980[a]		1990[a]		2000[a]	
Mode	MMB/D[b]	Percent	MMB/D[b]	Percent	MMB/D[b]	Percent
Passenger car	4.3	49	2.4-2.9	35	1.3-2.1	23
Light trucks	1.1	13	0.9	12	0.8	11
Other trucks	1.1	13	1.2	16	1.4	19
Other highway (buses, motorcycles, etc.)	0.1	1	0.2	3	0.2	3
Total highway	6.6	75[c]	4.7-5.2	65[c]	3.7-4.5	55[c]
Air	0.8	9	1.1	14	1.5	20
Marine	0.7	8	0.8	10	0.9	12
Rail	0.3	3	0.4	5	0.4	5
Pipelines[d]	0.1	1	0.1	1	0.1	1
Military Operation	0.3	3	0.3	4	0.4	5
Total nonhighway	2.2	25[c]	2.7	35[c]	3.3	45[c]
Total	8.8	100	7.4-7.9	100	7.0-7.8	100

[a] All fuel consumption numbers, except for passenger cars, from J. K. Pollard, C. T. Phillips, R. C. Ricci, and N. Rosenberg, "Transportation Energy Outlook: 1985-2000," U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-55-81-6, September 1981. Passenger-car fuel consumption from this study.

[b] 1B = 5.9 MMBtu.

[c] Sums may not agree due to round-off errors.

[d] Does not include natural gas.

SOURCE: Office of Technology Assessment.

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[20] J. K. Pollard, et al., "Transportation Energy Outlook: 1985-2000," Transportation Systems Center, U.S. Department of Transportation; DOT-TSC-RS-112-55-81-6, September 1981.

Some of the fuel economy gains for other transportation modes—as for passenger cars—will be offset by growth in miles traveled. Annual growth rates of 1 to 3 percent per year are expected for most modes of transport, although sales of light trucks have recently dropped to such an extent that mileage traveled by such vehicles may decrease in the years ahead. In total, fuel consumed for transportation is projected to decline from 8.8 MMB/D in 1980 to the range of 7 to 8 MMB/D by 2000, and then to rise slowly as diminishing returns set in.

Because of the differing growth rates for the various transportation modes and the differing magnitudes of the fuel economy improvements expected, the distribution of fuel use by mode will change. Passenger cars now account for half of all the fuel used in transportation. Their share will decrease to about 25 percent by the early part of the next century. Medium and heavy trucks currently consume 12 percent of all transportation fuel, a figure that could rise to 20 percent by 2000. Likewise, the percentage of transport fuels used by aircraft could nearly double.

COSTS OF INCREASED FUEL EFFICIENCY

Overview

Automobile manufacturers spend for many purposes—R&D, investment in plant and equipment, labor, materials, marketing, and administration. How much a particular manufacturer spends depends on the firm's financial capabilities, the rate of technology change, initial characteristics of the product line, and the state of existing manufacturing facilities.

R&D on vehicle designs and manufacturing processes is an important spending area. Development—on which most R&D money is spent, research expenditures being small by comparison—creates new product designs and production methods. Growth in R&D activity, required to support rapid changes in vehicle design, will raise both the total costs of automobile production and the proportion of development and other preproduction expenses.

In 1980, the four major domestic manufacturers spent almost $4.25 billion (1980 dollars) on R&D. For individual firms, this spending amounted to 2 to 5 percent of sales revenues. In addition, major parts and equipment suppliers spent about $293 million on automotive R&D in 1980. Together, major automobile manufacturers and suppliers spent over $4.5 billion on R&D for automobiles and other vehicles.[21]

Capital investment levels are even greater. These expenditures, which go hand-in-hand with design and development activities, are the largest single category of spending in automobile manufacturing. Major categories of capital goods include factory structures, production equipment such as machine tools and transfer lines, and a wide variety of special tools such as dies, jigs, and fixtures.

Manufacturers today are making investments to improve product quality, as well as increase productivity and cut costs. Flexible manufacturing is also becoming an increasingly attractive investment. Such sophisticated facilities are relatively expensive but may yield low operating costs and other long-term benefits. General Motors (GM), Ford, and Chrysler spent $10.8 billion (1980 dollars) on property, plant, equipment, and special tooling in 1980.[22]

Financing is an important aspect of capital investment. Historically, the automobile industry has financed capital programs with retained earnings, except during recessions when low sales generated inadequate revenues. Several current, and possibly enduring, factors—declining profitability, high inflation, slow market growth, market volatility, and consumer resistance to real price increases—have eroded manufacturers' ability to finance major capital programs from earnings (or by issuing stock), leading them to borrow funds and therefore to face potentially higher costs of capital. GM and Ford each borrowed over $1 billion during 1980; they may together borrow as much as $5 billion by the mid-1980's.[23]

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[21] "R&D Scoreboard: 1979," *Business Week*, July 7, 1980; "R&D Scoreboard: 1980," *Business Week*, July 6, 1981.

[22] Annual Reports for 1980.

Although domestic manufacturers have recently borrowed from foreign and other nontraditional sources, they are able to borrow only a limited portion of their capital needs (at acceptable interest rates). Borrowing in the United States has recently become more costly to automobile manufacturers because their bond ratings have been lowered, in recognition of the low profitability, high spending levels, and high risks that characterize today's auto market. Consequently, they are obtaining cash by restructuring their physical and financial operations (e.g., by selling assets and changing the handling of accounts receivable), engaging in joint ventures, and selling tax credits (under Economic Recovery Tax Act of 1981 leasing rules).

Automotive fuel economy improvement affects other costs as well, although not to the same extent that it affects R&D and capital investment. Costs for labor and materials depend on vehicle design and on production volumes and processes. For example, automated equipment reduces labor content; small cars require less material; and lighter body parts and more efficient engines may require new, relatively expensive materials (high-strength steels, aluminum alloys) and processes (heat treatments, longer weld cycles, a greater number of forming operations, slower machining). Reductions in the amounts of labor and materials used per car help offset inflationary and real increases in their costs. Labor costs, however, are slow to change in the short term because they are subject to union negotiations, and because contractual provisions constrain layoffs and require compensation payments.

Finally, spending on marketing and administration is not directly related to technological change or to production; although these expenses may be cut back to facilitate spending in other areas. During 1980, for example, auto manufacturers made large cuts in white collar staffs to lower administrative costs. However, marketing activities may increase because of heightened competition or the introduction of new products.

The remainder of this chapter focuses on capital costs, because they are the critical component of the overall costs of changing automobile designs. On a per car basis, however, labor and materials costs will remain higher than capital costs because of the ways different types of costs are allocated. The costs of capital goods (including financing) are recovered throughout their service life in vehicle prices. Since capital goods are used to produce many vehicles over many years (at least 30 years for plants, 12 years for much production equipment, and 3 to 5 years for special tooling), each vehicle bears a relatively small percentage of the costs of capital to produce it. In contrast, labor services and materials are effectively bought to manufacture each car.

Relative to other manufacturing costs, capital costs are expected to undergo the greatest percentage increase as manufacturers increase their output of fuel-efficient vehicles. Moreover, capital costs are becoming proportionately greater because capital goods are being purchased at faster rates and at higher real prices than historically, and because automotive production is becoming more capital-intensive as automation proceeds—i.e., more capital equipment is being used to produce automobiles relative to labor, materials, and other inputs. Consequently, capital costs will have an especially pronounced influence on the financial health of automobile manufacturers over the next two decades.

Investments to Raise Fuel Economy

Technology-Specific Costs

Table 30 presents capital cost estimates prepared by OTA for the technologies described earlier in this chapter, based on discussions with industry analysts and the most recently published analyses. However, they draw on the experience and expectations of the mid and late 1970's, when limited consumer demand for fuel economy led manufacturers to make conservative projections of vehicle design changes and high projections of costs. Because of recent surges in the demand for fuel economy and small cars, manufacturers now expect to make substantial im-

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[23] Also see "Producing More Fuel-Efficient Automobiles: A Costly Proposition," op. cit.

Table 30.—Post-1985 Automotive Capital Cost Estimates

	$M/500,000 units	Associated costs
Platform change		
Weight reduction, redesign	500-1,000	R&D[a], redesign
Material substitution	100-400	R&D[a], materials, labor
Engine change		
Improved SI[b], diesel,	50-250	R&D[a], redesign
New SI[b], diesel, DISC[c]	400-700	
Transmission change		
Improve contemporary drivetrains	100-400	R&D[a], redesign
New drivetrains—CVT[d], energy storage, engine on-off	500-700	R&D[a], redesign

[a] Capital costs for accessory and lubricant improvements and aerodynamic and rolling resistance reductions are not included separately. They may in total cost about $50M/500,000, an amount within the range of error implied by the above estimates. Note: aerodynamic improvements will be carried out with weight-reducing design changes; lubricant and tire changes are already being made by suppliers and may continue as a regular aspect of their businesses; and some accessory improvements are made regularly and as accompaniments to engine redesigns.

[b] Spark ignition.

[c] Direct injection stratified charge.

[d] Continuously variable transmission.

SOURCE: Office of Technology Assessment.

provements in fuel economy by the mid-1980's by accelerating technological change schedules and by increasing the proportion of small cars in the sales mix.

Note that increasing production volume for existing models is much cheaper than introducing new models; U.S. manufacturers could probably double their output of many existing models. The costs of design changes in the post-1985 period now seem even more uncertain, because earlier achievements will leave fewer and generally more costly options available.

Projecting costs for specific design changes is difficult, for several reasons. First, the redesign of any one vehicle component or subsystem often necessitates related changes elsewhere. Second, such changes may require new production processes. Third, actual costs to individual manufacturers are technology-specific and sensitive to several factors—technological development, production volume, vertical integration, the rate at which changes penetrate the fleet, and available manufacturing facilities. These factors are discussed below.

Technological Development.—Many technologies are inherently expensive due to materials requirements or complexity of design or manufacture. The diesel engine for passenger cars is a good example. Over time, experience with a new technology may lead to some cost reduction.

Production Volume.—Costs vary with production volume because equipment and processes are designed such that average product cost is lowest once a threshold production volume is achieved.[24] Because this minimum volume or scale grows as the production process becomes more highly automated, the rising capital intensiveness of automobile production increases the sensitivity of unit costs to production volume. Operating costs (comprised of labor, materials, and allocated marketing and administration costs) per unit are sensitive to production volume in the short term. For example, Ford's operating costs per dollar of sales were estimated to be under $0.90 in the first quarter of 1979, but subsequent sales declines brought them close to $1.05 by the fourth quarter of 1980.[25]

The cost estimates in table 30 assume uniform 500,000-unit capacities.* Cost estimates for uniform or optimal capacity levels provide a better measure for spending levels for the industry as a whole than for individual manufacturers because individual firms acquire different levels of capacity at different costs according to their financial ability, sales volume, and technological options. The costs of acquiring more or less than optimal capacity, however, are not linearly related to the level of capacity.

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[24] See K. Bhasker, "The Future of the World Motor Industry" (New York: Nichols Publishing Co., 1980.) The optimum production volumes may change with manufacturing technology, however.

[25] "Ford's Financial Hurdle: Finding Money is Harder and Harder," *Business Week*, February 1981.

*This procedure was also employed in the Mellon Institute study (Ref. 32) which drew on data provided by automobile manufacturers.

Vertical Integration.—Vertical integration refers to the degree to which a manufacturer is self-sufficient in production or distribution. Integration can reduce costs in two ways: 1) by eliminating activities and costs associated with the transfer of goods between suppliers and distributors (dealers), and the automakers themselves; and 2) by enabling manufacturers to optimize the flow of production and distribution. Major U.S. automobile manufacturers are highly integrated compared with firms in many other industries, although they are much less integrated than oil companies. Various U.S. automobile firms make steel, glass, electronic components, and robots, but overall they buy about half of their materials and other supplies. GM's greater vertical integration relative to other U.S. automobile manufacturers is one reason for its lower manufacturing costs. The high effective degree of vertical integration among Japanese auto manufacturers (over 80 percent for some firms) helps to make auto production in Japan cheaper than in the United States.*

Rate of Change.—The rate at which new technology is incorporated in automobiles influences cost in three important ways. First, the faster a design is implemented, the shorter are the product development, product and process engineering schedules, and the less likely is production to be at minimum cost, given scale. Second, increasing the rate of technological change raises the number and magnitude of purchases from suppliers. Third, a faster rate of change can make facilities and processes technologically obsolete, necessitating investments in replacements before original investments are recovered.

Available Facilities.—Opportunities for manufacturers to redesign their product lines are shaped by the characteristics of their base vehicles and existing production facilities. The technological scenarios described at the beginning of this chapter illustrate how paths of change may differ.

Estimates of manufacturing costs require evaluation of the requirements for implementing each combination of new technologies. Investment by different manufacturers to produce the same vehicle will differ because their initial facilities and vehicle designs provide different bases for change, and because manufacturers have choices in the timing and extent of major facility renovations, in balancing plant renovation and new construction, and the selection of new production equipment—e.g., degree of automation. Different production bases make rapid change more costly for some manufacturers than for others.

The variability in actual facilities costs is illustrated by recent projects associated with new vehicle designs. Chrysler spent over $50 million to renovate its Newark assembly plant to produce 1,120 K-cars per day.* Chrysler made similar alterations to its Jefferson Avenue (Detroit) assembly plant to enable K-car production at the same rate as at the Newark plant, but at a cost of $100 million. GM plans to spend $300 million to $500 million to build a new Cadillac assembly plant (replacing two old ones) on the Chrysler Dodge Main site in Michigan. The differences in these spending levels reflect different starting points and differing objectives. Since automation, quality control, and nonproduction aspects of the above projects contribute to other goals in addition to higher fuel economy, these examples illustrate how difficult it is to infer the specific costs of investments to raise fuel economy.

New Car and Fleet Investments

The incremental investments manufacturers make to raise automobile fuel efficiency will affect the costs of producing new cars and new-car fleets. To gage the effect of changing automotive technology on industry investment requirements, the costs of capacity associated with the high- and low-estimate scenarios were estimated by weighting and adding the costs of specific changes. This procedure produces crude estimates of the investments necessary to produce cars at fuel efficiencies projected in the scenarios.* Table 31 presents investment projections by scenario and by 5-year periods, and tables 32-34 present the derivation of table 31 in somewhat more detail.

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*These conditions reflect peculiarly close relationships between Japanese manufacturer and supplier firms even in the absence of formal linkages.

*The project entailed new plant layout; body shop renovation; conveyor system replacement and rearrangement; assembly tooling replacement; installation of automatic and computerized machine welding, transfer, and framing equipment; installation of new painting, front-end alignment, trim and cushion assembly equipment and additional quality control systems.

Adding the costs of specific technologies taken separately—for which cost data are available—is an imprecise way of estimating the costs of technology combinations embodied in new automobiles and fleets, because it does not capture the costs of implementing changes together. Very accurate investment estimates can be made by evaluating for specific new automobile designs the plant-by-plant changes in costs (for everything from property and construction to engineering and equipment to taxes), accounting for various economies (concurrent and sequentially introduced technologies may share plant, equipment, even special tooling) and extra costs for minor changes to the car during production.

Table 31.—Summary of Investment Requirements Associated With Increased Fuel Efficiency

		High estimate[a]			Low estimate[a]		
Year	Units	Large	Medium	Small	Large	Medium	Small
1985-90	$Mil./500,000	900-1,740	820-1,660	780-1,600	490-1,000	480-1,000	450-1,000
	$/car	180-350	160-330	150-320	100-200	100-200	90-200
1990-95	$Mil./500,000	570-1,100	570-1,100	610-1,200	520-940	520-930	500-900
	$/car	110-230	110-230	120-240	100-190	100-190	100-180
1995-2000	$Mil./500,000	350-950	370-980	350-950	480-860	520-930	500-900
	$/car	70-190	70-200	70-190	100-170	100-190	100-180

[a] See tables 23 and 24 for definitions of these scenarios.

SOURCE: Office of Technology Assessment.

Table 32.—Average Capital Investments Associated With Increased Fuel Efficiency by Car Size and by Scenario (1985-90)

	Percent of production facilities that incorporate new technologies or are redesigned					
	High estimate			Low estimate		
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE[a] $50-250M/500,000	30	70	95	60	80	100
Prechamber[b] $400-700M/500,000	15	—	5	15	10	—
Open chamber[c] $400-700M/500,000	30	20	—			
Transmissions						
Four-speed auto and TCLU[d] $300-500M/500,00	70	70	70	50	50	50
Platform						
Various[e] $500-1,000M/500,000	100	100	100	50	50	50
Capital costs for technology changes (weighted average)						
Total $M/500,000	$905-1,740	$825-1,665	$778-1,623	$490-1,005	$480-1,020	$450-1,000
Per car (total ÷ 500,000 ÷ 10)[f]	$181-348	$165-333	$156-325	$98-201	$96-204	$90-200

[a] Spark-ignition engine.

[b] Prechamber diesel.

[c] Open chamber diesel or open chamber stratified charge.

[d] Four-speed automatic with torque converter lockup.

[e] Weight reduction, material substitution, aerodynamic and rolling resistance reductions, improved lubricants and assessories.

[f] Vehicle change investments are divided by 10 to approximate amortization practices. Forty percent of capital spending goes for plant (30 year) and equipment (12 years), which may together be summarized as "facilities" and amortized over 15 years (Ford Motor Co. interview) $0.4 \times 3 + 0.6 \times 15 = 10.2$ or about 10 years.

SOURCE: Office of Technology Assessment.

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*Assuming that each technology is applied across the fleet at efficient volume, the calculations can be performed on a per-500,000 unit basis and scaled up or down to determine overall or implied per unit investments. The average investment to produce each size class in each period with projected technological characteristics may be calculated by weighing the cost of each technology (table 30) by its proportion of application and summing the weighted investments.

Table 33.—Average Capital Investments Associated With Increased Fuel Efficiency by Car Size and by Scenario (1990-95)

	Percent of production facilities that incorporate new technologies or are redesigned					
	High estimate			Low estimate		
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE $400-700M/500,000	15	25	35	25	35	50
Prechamber $400-700M/500,000	—	—	—	30	20	—
Open chamber $400-700M/500,000	40	30	30			
Transmissions						
CVT, four-speed auto and TCLU $500-700M/500,00	35	35	35	50	50	50
Engine on-off $500-700M/500,000	15	15	15			
Platform						
Various $100-400M/500,000	100	100	100	50	50	50
Capital costs for technology changes						
Total $M/500,000	$570-1,135	$570-1,135	$610-1,205	$520-935	$520-935	$500-900
Per car (total ÷ 500,000 ÷ 10)	$114-227	$114-227	$122-241	$104-187	$104-187	$100-180

SOURCE: Office of Technology Assessment.

Table 34.—Average Capital Investments Associated With Increased Fuel Efficiency by Car Size and by Scenario (1995-2000)

	Percent of production facilities that incorporate new technologies or are redesigned					
	High estimate			Low estimate		
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE $400-700M/500,000	15	15	35	15	25	10
Open chamber $400-700M/500,000	35	40	15	30	30	40
Transmissions						
CVT improved $100-400M/500,00	50	50	50	—	—	—
CVT $500-700M/500,000	—	—	—	35	35	35
Engine on-off $500-700M/500,000	—	—	—	15	15	15
Platform						
Various $100-400M/500,000	100	100	100	50	50	50
Capital costs for technology changes						
Total $M/500,000	$350-950	$375-985	$350-950	$480-865	$520-935	$500-900
Per car (total ÷ 500,000 ÷ 10)	$70-190	$74-197	$70-190	$96-173	$104-187	$100-180

SOURCE: Office of Technology Assessment.

The Transportation Systems Center of the U.S. Department of Transportation, for example, has developed a "surrogate plant" methodology to do this. The accuracy of this approach is based on detailed consideration of vehicle designs and the corresponding equipment and plant needs. The methodology requires specific projections of engineering changes that are beyond the scope of this report, and speculative for the 1990's.

Note that investment figures presented here apply only to investments required to raise the fuel economy of cars sold in the United States. Total capital spending reported by U.S. manufacturers also includes investment in nonautomobile projects (such as truck and military equipment production), investments in foreign subsidiaries, and spending for normal replacement of worn-out capital and for capacity improvement and expansion.

Note also that not all of a given investment may be associated with fuel economy improvement. For example, engines, transmissions, and car bodies are redesigned periodically. Changes of this sort cannot always be distinguished from those made for increased fuel efficiency, so the full cost of the investments shown in table 31 should not be allocated solely to fuel economy improvements.

The difficulty of allocating costs when a single investment produces several distinct results is a well-known problem of accounting,[26] and there is no fully satisfactory method for making the allocations. For the purposes of the fuel savings cost analysis in the next sections, it is assumed that the percentages shown in table 35 represent the share of investment costs attributable to increases in fuel economy. Engine and body redesigns are made for many reasons other than fuel efficiency. On the other hand, most of the advanced materials substitution (to plastics and aluminum) assumed in the scenarios, or automatic engine cutoff, probably would not be incorporated into cars by 2000 without the impetus for increased fuel efficiency. Advanced transmissions represent an intermediate case between these extremes.

The total capital investment associated with the production of fleets of given size mix is calculated by taking an appropriately weighted sum of investments by size class. Assuming that U.S. new-car sales average 11.5 million units in 1985-90, 11.7 million units in 1990-95, and 12.1 million units in 1995-2000 (conforming to growth rates projected earlier in this chapter); and assuming that imports throughout the 1985-2000 period average 25 percent of all sales (near recent levels), following the high-estimate scenario for the 15-year period may require $30 billion to $70 billion in investments and R&D expenditures. Following the low-estimate scenario may require about $25 billion to $50 billion (see table 36). If new-car sales are lower due to continued recession and consumers' stagnant real disposable income, then the investments would be proportionately smaller. For example, if domestic sales remain at 8 million vehicles per year (6 million domestically produced) between 1985 and 2000, then capital investments would be about two-thirds as large as shown in table 36 (but R&D costs could remain

Table 35.—Percentage of Capital Investments Allocated to Fuel Efficiency

Category	Percentage of investment allocated to fuel efficiency
Engine	50
Transmission:	
CVT, four- and five-speed auto and TCLV	75
Energy storage and engine on-off	100
Platform:	
Weight reduction (body redesign)	50
Materials substitution	100
Composite of all efficiency related investments:	
1985-90	55-65
1990-95	70-80
1995-2000	65-75

SOURCE: Office of Technology Assessment.

Table 36.—Total Domestic Capital Investments for Changes Associated With Increased Fuel Efficiency[a] (billion 1980 dollars)

Time of investment	High estimate[b]	Low estimate[b]
High car sales[a]		
1985-90	14-29	8-17
1990-95	10-20	9-16
1995-2000	7-18	9-16
Total	31-67	26-49
Low car sales		
1985-90	10-20	6-12
1990-95	7-14	6-11
1995-2000	4-12	6-11
Total	21-46	18-34

[a] Assumptions about car sales:

	High car sales
1985-90	11.5 million cars/yr
1990-95	11.7 million cars/yr
1995-2000	12.1 million cars/yr
	Low car sales
1985-2000	8 million cars/yr

Estimates also assume that imports average 25 percent of total car sales between 1985 and 2000.

[b] Within the uncertainties, the investment requirements are the same for all three sales-mix scenarios.

SOURCE: Office of Technology Assessment.

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[26] A. L. Thomas, "The Allocation Problem in Financial Accounting Theory" (Sarasota, Fla.: American Accounting Association, 1969), pp. 41-57, and A. L. Thomas, "The Allocation Problem: Part Two" (Sarasoto, Fla.: American Accounting Association, 1974.)

the same). If this happens, total investments plus R&D would be reduced by about 25 percent below those for the high car sales case.

The greater investments (per vehicle) associated with the high-estimate scenario reflect the fact that the scenario contains more extensive changes more often than the low-estimate scenario. In either case, however, there is no significant difference in the total investment for increased fuel efficiency for the different size-mix scenarios, since the rate of capital turnover for increased fuel efficiency is probably adequate to accommodate the mix shifts.*

OTA estimates of cumulative investments imply that manufacturers would make capital investments of $2 billion to $5 billion per year (1980 dollars) over about 15 years to implement the high-estimate scenario and about $2 billion to $3 billion per year to implement the low-estimate scenario in the case of high car sales. The corresponding figures would be about $1.5 billion to $3 billion and $1 billion to $2 billion, respectively, for low car sales.

Actual added capital spending levels by manufacturers are likely to be lower than indicated because some investments in technologies to raise fuel economy will take the place of investments in more conventional technologies that would normally be made as plant and equipment wear out. In fact, deducting the cost of changes that would have been made under normal circumstances,** but are obviated by or could be incorporated in the investments shown in tables 32-34, could reduce the added investment cost of implementing the scenarios by two-thirds in the high estimate and by about 80 percent in the low estimate, leading to capital investments averaging $0.3 billion to $0.7 billion per year for the low estimate (high car sales) and $0.6 billion to $1.5 billion per year for the high estimate (high car sales) above "normal."

Spending by the automakers will be reduced to the extent that they buy rather than make various items; to the extent that U.S. suppliers provide purchased items, the total investment levels can be viewed as spending estimates for U.S. automakers and suppliers together. However, joint ventures with foreign firms, erection of foreign plants with foreign government aid and relatively labor-intensive designs, and purchases of parts and knocked-down vehicle kits from overseas would all lower investment costs to U.S. firms. So would an increase in import penetration. Finally, note that future levels of normal capital spending, however they are determined, may be higher than past levels if competition from foreign manufacturers makes it "normal" frequently spend to improve fuel economy and to modernize facilities.

Fuel Savings Costs

To compare the costs and gains of saving fuel by raising automobile fuel economy with the costs and gains through other means, it is useful to express costs in terms of a common measure such as dollars per quantity of oil (gallons or barrels-per-day) saved. To measure the total dollars per quantity of oil saved implied by raising fuel efficiency requires estimating changes in variable (labor and materials), fixed capital and R&D costs.

OTA was unable to obtain or develop reliable variable cost figures for technologies discussed in this report, because information about variable costs, which vary considerably between companies, is proprietary and speculative for the 1990's. Four general observations about variable costs of raising fuel economy can be made: First, implementing some new technologies, including certain weight-reduction measures (e.g., smaller engines and body frames), will lower variable costs by reducing labor and materials requirements. Second, automation will lower labor requirements. Third, using some new technologies, such as four- and five-speed transmissions and alternative engines, will raise variable costs because they are inherently more complex than conventional technologies. Fourth, use of new materials will raise variable costs. The net change in variable costs is uncertain and will depend heavily on basic materials costs and the success of adapting the new designs to mass production. Note that variable costs have been about three times the level of fixed costs for the average car or light truck.

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*On the average, over 50 percent of engines, transmissions, and bodies are being redesigned during each 5-year period for increased fuel efficiency, whereas the mix shift requires 10 to 20 percent change during each 5-year period.

**Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced materials substitution.

Based on the percentages shown in table 35, however, table 37 shows the capital investment attributable to increased fuel efficiency per gallon of gasoline equivalent saved, assuming the average car is driven 100,000 miles and the average service life of the investment is 10 years. In all cases, the investment cost is less than $1.00 per gallon saved. If, however, accelerated capital turnover reduces the useful service life of the investment to 5 years, the costs would be twice those shown in table 37. Conversely, if automobiles are kept longer and driven further in the future, then the cost per gallon is reduced. For example, if cars are driven 130,000 miles over their lifetime, on the average, the costs would be 75 percent of those shown in table 37.

The final cost category considered here is the product development cost. Although it is difficult to make detailed predictions of the costs of development, U.S. automobile manufacturers spent from 40 to 60 percent as much on R&D (mostly development) during the 1970's as they spent on capital investments.[27] During 1978 and 1979, R&D averaged about 40 percent of capital investments.

In order to compare the investments for increased fuel efficiency in automobiles with those for synfuels, it is convenient to express them as the investment cost attributable to fuel efficiency plus the associated R&D expenditures per barrel per day oil equivalent saved by these investments. Assuming that development expenditures are 40 percent of capital investment, the costs in table 37 can be converted to the investments shown in table 38 for individual cars and fleet averages between 1985 and 2000. The combined R&D and capital costs appear to increase somewhat from the 1985-90 period to the 1990-95 period. However, technical advances by the early 1990's could prevent further increases during the late 1990's.

Table 37.—Estimated Capital Investment Allocated to Fuel Efficiency per Gallon of Fuel Saved

	High estimate			Low estimate		
	Car size:			Car size:		
	Large	Medium	Small	Large	Medium	Small
1985						
Mpg	27	39	48	23	35	45
1990						
Mpg	37	51	62	28	41	52
Gallons saved/yr[a]	910	550	430	705	380	270
Investment ($/car)[b]	100-190	90-180	90-180	60-110	60-110	50-110
Dollars per gallon[c]	0.11-0.21	0.17-0.34	0.21-0.42	0.08-0.16	0.15-0.30	0.19-0.41
1995						
Mpg	43	61	74	31	45	57
Gallons saved/yr[a]	340	290	240	310	200	150
Investment ($/car)[b]	80-180	80-180	90-180	70-130	70-130	70-130
Dollars per gallon[c]	0.24-0.51	0.29-0.60	0.37-0.77	0.22-0.42	0.35-0.67	0.44-0.83
2000						
Mpg	50	70	85	35	50	65
Gallons saved/yr[a]	260	210	150	260	200	190
Investment ($/car)[b]	50-150	50-150	50-150	70-130	70-140	70-140
Dollars per gallon[c]	0.18-0.56	0.24-0.71	0.33-0.99	0.27-0.50	0.36-0.68	0.36-0.68

[a] Fuel consumption of car relative to fuel consumption of comparable car 5 years earlier. Assumes 100,000 miles driven over life of car and on-the-road fuel efficiency 10 percent less than the EPA rated mpg shown.
[b] The investment attributed to fuel efficiency assuming an average life of 10 years for the investment. Also assumes production at rated plant capacity during the 10 years. Does not include R&D costs, which would add about 40 percent to the cost.
[c] The investment per car divided by the fuel saved over the life of the car.

SOURCE: Office of Technology Assessment.

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[27] G. Kulp, D. B. Shonka, and M. C. Halcomb, "Transportation Energy Conservation Data Book: Edition 5," Oak Ridge National Laboratory, ORNL-5765, November 1981.

Table 38.—Capital Investment Attributed to Increased Fuel Efficiency Plus Associated Development Costs per Barrel/Day of Fuel Saved

Car size	New-car fuel efficiency at end of time period[a] (mpg)	Capital investment plus associated development costs (thousand 1980 $ per B/D oil equivalent fuel saved)[b]
1985-90		
Large	28-37	19-51
Medium	41-51	35-81
Small	52-62	47-100
Average A[c]	38-48	21-57[d]
Averge B[c]	43-53	21-60[d]
1990-95		
Large	31-43	53-120
Medium	45-61	69-160
Small	57-74	89-200
Average A[c]	43-59	58-120[d]
Average B[c]	49-65	64-140[d]
1995-2000		
Large	34-49	44-130
Medium	50-71	57-170
Small	65-84	78-240
Average A[c]	51-70	48-150[d]
Average B[c]	58-78	50-150[d]

[a] EPA rated 55/45 city/highway fuel efficiency of average car in each size class.

[b] Assumes development costs total 40 percent of capital investments and that a car is driven 10,000 miles per year on averge. A barrel of oil equivalent contains 5.9 MMBtu.

[c] Averages A and B are based on the moderate and large mix shift scenarios, respectively.

[d] Averages are calculated by dividing average investment for technological improvements by fuel savings for average car at end of time period relative to average car at beginning of time period. The resultant average cost per barrel per day is lower than a straight average of the investments for each car size because of mathematical differences in the methodology (i.e., average of ratios v. ratio of averages) and because extra fuel is saved due to demand shift to smaller cars. The averaging methodology used is more appropriated for comparisons with synfuels because it relates aggregate investments to aggregate fuel savings. It should be noted that the cost of adjusting to the shift in demand to smaller sized cars is not included. Only those investments which increase the fuel efficiency of a given-size car are included. However, given the rate of capital turnover assumed for the scenarios, adjustments to the shift in demand probably can be accomodated within the investment costs shown.

SOURCE: Office of Technology Assessment.

Note that the costs and fuel savings benefit of improving fuel economy are incurred at different times by different parties. Manufacturer (and supplier) investments are made prior to production: 30 percent of capital spending occurs 12 to 24 months before first production, 65 percent occurs within the 12 months preceding production, and 5 percent occurs after production begins.[28] R&D costs may occur 5 to 7 years before first production. Fuel savings begin only after a vehicle is purchased, and they accrue over several years. Fuel savings benefit the consumer directly and the industry only indirectly.

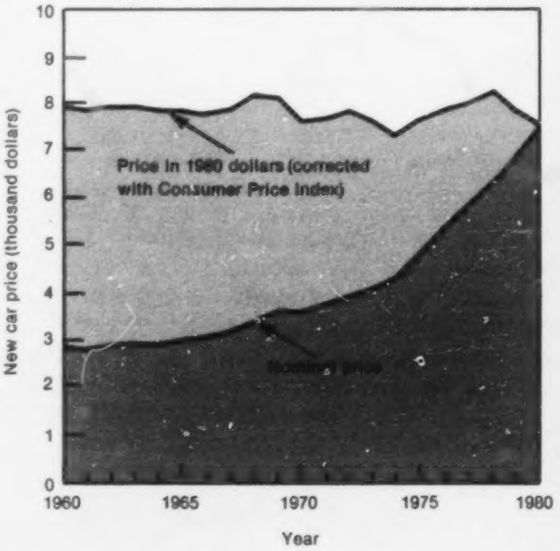
Consumer Costs

Automotive fuel economy improvements can affect costs to consumers through changes in real car purchase prices and changes in real costs of maintaining and servicing cars.

Prices

Trends in average car prices are easier to predict than trends in prices for specific car classes or models, because manufacturers have flexibility in pricing models and optional equipment. Real car prices (on which consumers base their expectations) have been relatively stable over the last 20 years (see fig. 12), although nominal car prices have risen steadily since the mid-1960's, because of general inflation. Labor and materials cost increases are not necessarily passed on to consumers. For example, the General Manufacturing Manager of GM's Fisher Body Division observed in a recent interview that although raw materials and labor costs have been rising about 11 to 12 percent annually, only 7 to 8 percent of those increases have been recovered through price, with improvements in productivity helping to control costs.

Figure 12.—Real and Nominal U.S. Car Prices, 1960-80



SOURCE: Bob Clukas, Bureau of Economic Analysis, U.S. Department of Commerce, private communication, 1981.

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[28] Harbridge House, Inc., *Energy Conservation and the Passenger Car: An Assessment of Existing Public Policy,* Boston, July 1979.

Where expenses increase faster than prices, manufacturers can still make profits by charging higher prices for those options or car models for which consumer demand is relatively insensitive to price. This flexibility is eroded when large proportions of automotive costs increase due to rapid and extensive change. Some industry analysts expect that through the mid-1980's, large capital spending programs and real increases in labor and materials costs will lead to increases in real car prices of up to 2 percent per year (approximately half of which reflects capital costs); more rapid automotive change might lead to even greater increases.[29]

Two percent of today's average car price (about $8,000) is about $160, although prices of individual cars will rise by greater and lesser amounts. OTA's scenario analysis suggests that investment costs alone for 5-year periods could range from $50 to $350 per car (assuming 10-year amortization periods for plant and equipment). The Congressional Budget Office (CBO), for comparison, concluded that average automobile production costs may increase by about $560 between 1985-95 because new technologies will cost that much (per car, on average) to implement.[30] These analyses may overstate the average amount of capital cost increase, because when new technologies replace old ones, the capital costs charged to old "technologies" should drop out of the vehicle cost calculation (unless old equipment is made obsolete prematurely). Actual cost increases will also depend on changes in variable costs, as illustrated below.

Table 39 shows two plausible estimates of consumer costs (per gallon of fuel saved) for increased fuel efficiency, based on the analysis in this chapter. The lower costs are calculated assuming that labor and material (variable) costs are no higher for more fuel-efficient cars than for cars being produced in 1985.[31] The higher costs include variable cost increases that are twice as large as the capital charges associated with increasing fuel efficiency.[32]

Although the range varies from costs that are easily competitive with today's gasoline prices to levels much above those prices, OTA does not believe that future variable costs can be predicted with sufficient accuracy to warrant more detailed estimates of variable costs. Table 39 should therefore be viewed as illustrative; actual consumer costs will depend on many factors, including the success of new production technologies.

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[29] Maryann N. Keller, *Status Report: Automobile Monthly Vehicle Market Review*, Paine Webber Mitchell Hutchins, Inc., New York, February 1981.

[30] Congressional Budget Office, *Fuel Economy Standards for Passenger Cars After 1985*, 1980.

[31] Richard L. Strombotne, Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safey Administration, U.S. Department of Transportation, private communication, 1981.

[32] Richard H. Shackson and H. James Leach, "Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete With OPEC Oil," Energy Productivity Center, Mellon Institute, Arlington, Va., Interim Report, Aug. 18, 1980. Variable cost changes were deduced from the estimates of capital investment and changes in consumer costs by assuming an annual capital charge of 15 percent of the investment and deducting this capital charge from the consumer cost estimate.

Table 39.—Plausible Consumer Costs for Increased Automobile Fuel Efficiency Using Alternative Assumptions About Variable Cost Increase

			Consumer cost[a] ($/gal gasoline saved)	
Time period	Mix shift	Average fuel efficiency at end of time period (mpg)	Assuming no variable cost increase relative to 1985 variable costs of production	Assuming variable cost increase equal to twice the capital charges
1985-90	Moderate	38-48		
	Large	43-53	0.15-0.40[a]	0.40-1.10[b]
1990-95	Moderate	43-59		
	Large	49-65	0.35-0.85[b]	1.10-2.60[b]
1995-2000	Moderate	51-70		
	Large	58-78	0.30-0.95[b]	0.90-2.80[b]

[a] Assumes annual capital charges of 0.15 times capital investment allocated to fuel efficiency, no discount of future savings, and car driven 100,000 miles during its lifetime.
[b] Within the uncertainties the costs are the same for each mix shift.

SOURCE: Office of Technology Assessment.

Individual car prices will not necessarily change in proportion to their costs, in any case. Specifically, there are three reasons why it is difficult for U.S. manufacturers to finance automotive changes through price increases: competition from lower cost imports, the relationship between new and used car prices, and limited consumer willingness to tradeoff high car prices against lower gasoline bills. First, because high fuel-economy imports from Japan cost about $1,000 (1980 dollars) less than American-made cars,[33] U.S manufacturers have little freedom to raise prices without losing sales volume to imports (all things equal). International cost differences may narrow in the future, however, as foreign labor costs rise and if U.S. productivity increases.

Second, the effective price of new cars for most buyers includes a trade-in credit on an older car. Decline in demand for used cars, which might occur if older cars were significantly less fuel efficient than new ones and if maximum fuel economy were in demand, would effectively raise the price of new cars. This phenomenon would hinder a rapid mix shift.

Third, consumers may resist high prices for fuel-efficient cars because they tend to discount such future events as energy cost savings rather heavily, by perhaps 25 percent or more.[34] Discounting at high rates would cause consumers to demand relatively large amounts of fuel savings in return for a given increase in price. Each gallon saved seems to cost more if consumers discount at high rates, because discounting reduces the perceived number of gallons saved over the life of the car.

This phenomenon can be illustrated as follows: The undiscounted lifetime fuel savings from raising a car's fuel economy from 45 to 60 mpg is 557 gal; at a 25 percent discount rate the discounted savings is 227 gal (using a declining schedule of yearly fuel consumption) or about 40 percent of the actual savings. If it costs $150 to $350 per car to raise the fuel economy from 45 to 60 mpg, the cost per gallon saved would be $0.27 to $0.63 without discounting but about 2.5 times as much, $0.66 to $1.54, if fuel savings are discounted at 25 percent. Consumer behavior may be at odds with the national interest, because future savings of oil have a relatively low "social" discount rate for the Nation.

Maintenance

Automotive maintenance and service costs may increase with vehicle design change but the amount of increase depends on institutional as well as technological change. Manufacturers are modifying car designs to make servicing less frequent and less expensive, but—with more complex and expensive components in cars—there is a definite potential for increased repair costs. Also, use of new equipment, including electronic diagnostic units, may lead to higher real costs for service. For smaller shops, in particular, lack of familiarity with new technologies and problems with multiple parts inventories (necessary for servicing new- and old-technology cars) could add to consumer service costs. Because dealerships and larger service firms are in a better position to adjust to changing technology, they are likely to gain larger shares of the service market.

Available estimates of service cost changes for future cars are very speculative. For instance, CBO has estimated that maintenance and service costs associated with transmission improvements, adding turbochargers, and altering lubricants could raise discounted lifetime maintenance costs of new cars by $40 to $90 on average (assuming a 10 percent discount rate). The actual changes in maintenance costs, however, will depend heavily on the success of development work aimed at maintaining automobile durability with changing technology.

Electric and Hybrid Vehicles

Costs of producing electric (EV) and hybrid vehicles (EHV) will differ from those of producing conventional vehicles. EVs substitute batteries, motors, and controllers for fuel-burning engines and fuel tanks. Hybrid vehicles include most or all of the components of conventional vehicles as well as EVs, but in modified forms. The components required for electric propulsion, which contribute directly to vehicle cost, further add indirectly to cost because they change the structural requirements of the vehicle. The size and weight of batteries, in particular, increase the need for space and structural strength,[35] necessitating changes in vehicle design and weight increases.

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[33] *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles*, op. cit.

[34] Evidence of high consumer discount rates for energy- efficient durable goods is presented in an article by J. A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *Bell Journal of Economics*, vol. 10, No. 1 (spring 1979), and in a "Comment" article by Dermot Gately in the same journal, vol. II, No. 1 (Spring 1980).

Batteries are a major source of both direct and indirect cost. They may comprise 25 percent of total cost, depending on type, size,and capacity.* Batteries available for electric vehicles by 1990 may be priced (1980 dollars) at $1,700 to $2,700 (corresponding to production cost of $1,300 to $2,100) while advanced batteries available by 2000 may be priced below $2,000 (with production cost around $1,500).[36]

Electric motors are smaller, lighter, and simpler than internal combustion engines. Motor controllers, however, are relatively bulky and may be more expensive than the motors themselves, depending on their design. Motor-controller combinations likely to be available by 1990 may cost around $1,000.*

Estimates given in the report cited in footnote 36 suggest that near-term EVs and EHVs would cost at least 50 percent more than comparable conventional vehicles. Technological advances in battery development could reduce electric and hybrid vehicle costs, however. Note that manufacturers may initially set the prices of EVs close to those of conventional cars to enhance their appeal to consumers.

Methanol Engines

Production of automobiles designed to run on methanol entails only minor modifications of the engine and fuel system. Consequently, the cost increase for engines designed to use methanol are minor. However, the cost of modifying an engine to operate efficiently on a fuel for which it was not designed can be more significant. One estimate is that retrofitting a gasoline-fueled vehicle for methanol use would cost $600 to $900, and redesigning an engine for methanol combustion would cost $50 to $100 per vehicle.[37] Ford, which is converting several Escorts to methanol combustion for the Los Angeles County Energy Commission, estimates that necessary modifications cost about $2,000 per vehicle, although they would cost less if larger numbers of cars were converted.[38]

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[35] CBO, op. cit.

*Batteries may comprise about 25 to 30 percent of the weight of an electric vehicle and about 20 to 25 percent of the weight of a hybrid vehicle. The electric motor and controller may comprise about 10 percent of an electric or hybrid vehicle's weight.

[36] W. M. Carriere, W. F. Hamilton, and L. M. Morecraft, General Research Corp., Santa Barbara, Calif., "The Future Potential of Electric and Hybrid Vehicles," contractor report to OTA, August 1980.

*Battery size is a function of the number and size of constituent cells. Battery capacity—and therefore vehicle driving range—is a function of the amount of energy deliverable by each pound of battery.

[37] William Agnew, G.M. Research Laboratories, private communication.

[38] "Ford Converts 1.6L Escorts for Methanol," *Ward's Engine Update*, Feb. 15, 1981.

APPENDIX A.—PROSPECTIVE AUTOMOBILE FUEL EFFICIENCIES

Table 5A-1 summarizes the prospective automobile fuel-efficiency increases used in OTA's analysis. The technologies involved are described in more detail below. In addition, alternative heat engines are discussed and the reasons for not including them in the projections to 2000 are explained.

More or Less Conventional Engines

There is more diversity among the engine technologies listed in table 5A-1 than in any other category. The table indicates increases in fuel economy of 15 percent at most for vehicles using improved SI engines compared with the baseline 1985 car—everything else remaining the same. Sources of such improvements include:

- smaller engines, because lighter cars will not require as much power and because the engines themselves will also continue to decrease in weight;
- decreases in engine friction—e.g., from new piston ring designs, smaller journal bearing diame-

Table 5A-1.—Prospective Automobile Fuel-Efficiency Increases, 1986-2000

	Percentage gain in fuel efficiency[a]					
	High estimate			Low estimate		
Technology	1986-90	1991-95	1996-2000	1986-90	1991-95	1996-2000
Engines						
Spark-ignition (SI)	10	10-15	15	5	5-10	5-10
Diesel:						
Prechamber	15	15		15	15	
Open chamber	25	35	35	20	20	25
Open chamber (SI) stratified charge (SC)		15	20			
Hybrid diesel/SC			35			
Transmissions						
Automatic with lockup torque converter	5	5	5	5	5	5
Continuously variable (CVT)		10	15			10
Engine on-off		10	10			10
Vehicle system						
Weight reduction (downsizing and materials substitution)	8	13	18	4	8	10
Resistance and friction (excluding engine)						
Aerodynamics	2	3	4	1	2	3
Rolling resistance and lubricants	1	2	3	1	1	2
Accessories	2	3	4	1	1	2

[a] Improvements in fuel efficiency are expressed as percentage gain in mpg compared with an anticipated average 1985 passenger car. The 1985 average car used as a reference has an inertia weight of about 2,500 lb, is equipped with spark-ignition engine, three-speed automatic transmission, and radial tires, and has an EPA mileage rating (55 percent city, 45 percent highway) of 30 mpg. The fuel efficiencies of the individual baseline cars, which are used to calculate future fuel efficiencies in each size class, are given in tables 23 and 24. Percentages are given on an equivalent Btu basis where appropriate—e.g., for diesels, which use fuel having higher energy content per gallon than gasoline, the percentage gain refers to miles per gallon of gasoline equivalent, which is 10 percent less than miles per gallon of diesel fuel. The table does not include efficiency improvements from alternate fuels such as alcohol.

SOURCE: Office of Technology Assessment.

ters, increases in stroke-to-bore ratios, improved engine oils;

- new combustion chamber designs, particularly fast-burn chamber geometries that permit lean operation at higher compression ratios;
- further refinements to electronic engine control systems (although most of the possible gains will have been achieved by 1985); and
- decreases in heat losses, consistent with allowable thermal loadings of internal engine parts and the octane ratings of available fuels.

Friction, which goes up with displacement, is a major source of losses in piston engines. Smaller engines cut friction losses, and also operate with less throttling—another source of losses—under normal driving conditions. Turbocharging is one way to make the engine smaller, improving fuel economy without sacrificing performance—albeit at rather high cost. Adding a turbocharger can help a small engine meet transient peak power demands and improve the driving-cycle fuel economy of both SI and CI engines by perhaps 5 to 10 percent—provided economy and not performance is the goal. Further applications are possible if the benefits perceived by consumers outweigh the price increases.

Bigger gains over the 1985 baseline SI powered car are possible with CI engines (table 5A-1). In the past, most efforts on diesels have been directed at heavy-duty applications such as trucks. Although the efficiency advantage of CI engines relative to SI engines decreases as engines become smaller, considerable scope remains for improving the driving-cycle efficiency of passenger-car diesels. In particular, all diesel engines now used in passenger cars are based on a "prechamber" design (also termed indirect injection). The combustion chambers in such engines consist of two adjoining cavities, with fuel injected into the smaller prechamber. At present, prechamber engines have several advantages for passenger vehicles. They are quieter than open-chamber (or direct injection) diesels, have wider ranges of operating speeds, and lower-cost fuel injection systems; in addition, emissions control is easier and smoke limitations are not as serious.[39]

As development of open-chamber diesels for passenger cars continues, substantial fuel-economy improvements can be expected—perhaps 15 percent above the levels that might be achieved with prechamber diesels, themselves of course considerably better than SI engines (table 5A-1)—assuming NO_x and particulate emissions can be controlled, and noise held to acceptable levels. The efficiency advantages of the open chamber engine stem largely from higher volumetric efficiency, lower heat losses, and more rapid combustion. Estimates[40] indicate that a 1.2-liter open chamber diesel in an automobile with an inertia weight of 2,000 lb should be able to achieve a 55/45 EPA fuel-economy rating of 60 to 65 mpg (with a manual transmission). Such estimates assume emissions standards for CI engines that do not severely compromise efficiency. Standards for NO_x and for particulates—which, besides making diesel exhaust smoky, are health hazards—are the most difficult to meet. In general, measures that reduce NO_x increase particulate emissions, and vice versa. To some extent, diesel engines will probably face continuing sacrifices in fuel economy to meet emissions standards.

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[39] "Future Passenger Car Diesels May Be Direct Injection," *Automotive Engineering*, June 1981, p. 51.

To emphasize efficiency gains rather than differences in the energy content of various fuels, the diesel engine improvements listed in table 5A-1 are all based on miles per gallon of gasoline equivalent. Because diesel fuel contains more energy (Btu) per gallon than gasoline, miles per *gallon* of diesel fuel would be 10 percent greater than miles per gallon of gasoline equivalent. For example, a 1990 prechamber diesel is expected to be about *10 percent more efficient* than an SI engine in the low estimate, *but about 20 percent better in terms of miles traveled per gallon of fuel.*

Stratified-charge (SC) engines (table 5A-1) are SI engines that have some of the advantageous features of diesels—such as potentially higher efficiency and potentially easier control of emissions, although low emissions levels have been difficult to achieve in practice—as well as the disadvantages of diesels, such as higher production costs.[41] SC engines, like diesels, operate with a heterogeneous distribution of fuel and air in the combustion chamber. But unlike diesels, the SC engines now in production burn gasoline and use spark plugs. SC engines, again like diesels, come in two varieties--prechamber, such as the Honda CVCC engine that has been sold in the United States since 1975, and open-chamber (also called direct injection). Prechamber engines have shown little if any fuel economy advantage, while open chamber SC engines promise good efficiencies in theory but have not yet been successfully reduced to practice. As with open-chamber diesels, it has proven difficult to achieve good response and smooth operation over the relatively wide range of loads and speeds needed for passenger cars. Moreover, open-chamber SC engines have the most potential in larger engine sizes; for a smaller engine operating at a higher load level—a situation now more prevalent—one of the major advantages of the SC engine, its lower throttling requirement, is less of a factor. Such an engine would be more costly to produce than a conventional SI engine, though less expensive than a diesel.

Another potential advantage of open-chamber SC engines is their tolerance for a wide range of fuels—including both gasoline and diesel, as well as alcohols and other energy carriers not necessarily based on petroleum. The broad fuel-tolerance of SC engines has led to a good deal of work directed at military applications. Further, the low-emissions potential of SC engines provided early stimulus for R&D directed at automotive applications. Open-chamber SC engines could find a place in passenger cars during the 1990's if the remaining problems are overcome.

Another possible path leads to a merging of diesel and SC engine technologies (table 5A-1). This might be visualized as a diesel with spark-assisted ignition. Spark-ignition would increase the tolerance of the engine to fuels with poor ignition quality (i.e., to fuels with a low cetane numbers such as gasoline or alcohols), but the combustion process would be more nearly a constant pressure event, as in a diesel.

Gas Turbine, Brayton, and Stirling Engines

Prospects for other "alternate engines" remain dim; in particular, most alternatives to SI and CI engines are poorly suited to small cars. Candidates include gas turbines (i.e., those operating on a Brayton cycle), or the Stirling cycle powerplants that have also been widely discussed for automotive applications. At present, such alternatives to SI and CI engines suffer many drawbacks. Gas turbines, for example, would need ceramic components to achieve high efficiencies at low cost—most critically in the power turbine, because high turbine inlet temperatures are needed to raise the efficiency. Ceramics are inherently brittle, and a great deal of work remains to be done before durable and reliable engine parts can be mass-produced from materials such as silicon nitride. The technical problems are more severe for highly stressed moving parts such as turbine rotors than for the applications such as combustor heads envisioned for Stirling engines. While the problems of developing tough ceramics for high-temperature applications in energy conversion devices are receiving considerable R&D support, success cannot be guaranteed. Even if the ceramics can be developed successfully this will not necessarily suffice to make gas turbines (or Stirling-cycle powerplants) practical for use in passenger cars.

With or without ceramic components, automotive gas turbines would, at least initially, be high in cost; and beyond high costs, they suffer a number of other disadvantages as automobile engines. Although gas turbines are highly developed powerplants in the large sizes used for stationary power or for marine and aircraft applications (500 hp and above) and ceramic components would allow higher operating temperatures and theoretically high efficiencies, turbine engines do not scale down in size as well as reciprocating engines. Both compressors and power turbines lose efficiency rapidly as their diameters decrease toward the sizes needed for smaller cars (75 hp and below). Brayton-cycle powerplants also have generally poor part-load fuel economy—which is a severe disadvantage in an automobile, where low-load operation is the rule. Furthermore, they need complex transmissions because the power turbine runs at speeds much higher than those of reciprocating engines. Fixed-shaft turbines, in particular, pose difficult problems in matching engine operating characteristics to automobile driving demands. But the most critical drawback of gas turbine powerplants is finally that they are unlikely to achieve competitive efficiencies when sized for small cars—those in the vicinity of 2,000 lb. As these size classes become a larger fraction of the market, the prospects for automotive gas turbines grow dimmer.

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[40] Ibid.

[41] J. A. Alic, op. cit.

Stirling-cycle engines are at much earlier stages of development. High efficiency in small sizes is a more realistic possibility for a Stirling engine than for a gas turbine, but the costs of Stirling engines are likely to be even higher than those for gas turbines[42]—and both engines will probably always be more expensive to manufacture than SI engines. Like turbines, ceramic components will be needed to achieve the best possible efficiencies in Stirling-cycle powerplants—here the most immediate needs are probably in the heater head and preheater. Seals have also been a persistent block to practical Stirling-cycle powerplants.

Both gas turbine and Stirling engines—because combustion is continuous—have intrinsic advantages in emissions control, and can burn a wide range of fuels. But intermittent-combustion engines (e.g., SI and CI) have thus far demonstrated levels of emissions control adequate to meet regulations. Broad fuel tolerance is again not unique to gas turbine and Stirling engines. These advantages are probably not enough to overcome the drawbacks of such engines, at least over the next 20 years.

Transmissions

Table 5A-1 lists a pair of developmental paths for automatic transmissions. (Manual transmissions are not explicitly included in the table; although more American purchasers are now choosing manual transmissions as small cars take a greater share of the market, automatics still predominate.) Geared automatic transmissions with lockup torque converters are already available in some cars; these are straightforward extensions of current technology, in contrast to continuously variable transmissions (CVTs). In principle, an engine on-off feature—in which the powerplant can be automatically shut off when not needed—could be implemented with either system (or with manual transmissions). Placing the engine drive shaft parallel to wheel axles would also yield a small improvement in fuel economy—because crossed axis gears could be replaced by more efficient parallel axis gears, or chains.

Geared automatic transmissions with either three or four speeds and a lockup torque converter—or with a split power path, an alternate method for minimizing converter slip and the consequent losses—are already on the market. A fourth gear ratio gives a better match between engine operating characteristics and road load demands. The fourth speed, for example, may function as an "overdrive" to keep engine load and efficiency high at highway driving speeds. Neither development—bypassing the torque converter when possible, or adding a fourth speed to an automatic transmission—is new, but the added costs of such designs are now more likely to be judged worthwhile. Many manual transmissions incorporate five rather than four speeds for similar reasons—the added gear benefiting fuel economy, as well as performance at low power-to-weight ratios.

Although the efficiencies of manual transmissions are greater than for automatics—that is, less of the power passing through the transmission is dissipated—the fuel economy achieved by many drivers may be as high or higher in cars equipped with an automatic transmission. By relying on the logic designed into the transmission to chose the appropriate gear ratio for given conditions, wasteful driving habits—e.g., using high engine speeds in intermediate gears—can often be avoided.

Further improvements in the control systems for automatic transmissions, as well as other changes such as variable displacement hydraulic pumps, will help to counterbalance their inherently lower efficiencies. In the past, automatic transmissions have depended on hydromechanical control systems—just as engines have. Hydromechanical control—although well developed and effective—limits the number of parameters that can be sensed, as well as the logic that can be employed. In the past, automatic transmissions have generally decided when to shift by measuring engine speed, road speed, and throttle position. By moving to fully electronic control systems, a greater number of engine parameters can be measured, and more sophisticated control algorithms implemented—enabling the transmission to be "smarter" in selecting among the available speeds. Electronics might also be used with manual or semiautomatic transmissions to help the driver be "smarter."

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[42] "Alternate Powerplants Revisited," *Automotive Engineering*, February 1980, p. 55.

As pointed out above, increasing the number of speeds in an automatic or manual transmission—from three to four or five—can help fuel economy. Although trucks often have many more speeds (for reasons beyond fuel economy), mechanical complexity (in automatics) and the demands on the driver (for manual transmissions)—as well as rapidly diminishing returns when still more speeds are added—will probably continue to limit the number of discrete gear ratios in passenger-car transmissions to four or five. If, however, discrete gearing steps can be replaced by a stepless CVT, then the engine could operate at the speed and throttle opening (or fuel flow for a diesel) that would maximize its efficiency for any road-load demand—i.e., engine speed would be largely independent of vehicle speed.[43] If otherwise practical, such a transmission could give markedly better fuel economy than other automatic transmissions—provided the CVT itself was reasonably efficient. Smooth, shiftless operation is another potential advantage of CVTs.

Continuously variable speed ratios can be accomplished in a variety of ways—e.g., the hydrostatic transmissions sometimes used in farm and construction equipment. A series hybrid electric vehicle—in which the engine drives a generator, with the wheels powered by an electric motor, typically drawing from batteries as well as the generator—in effect uses the motor-generator set as a CVT. Hydrostatic or electric CVTs are expensive and inefficient. CVTs used in past applications to passenger cars have generally been all-mechanical—e.g., based on friction drives, or belts. Typically, such designs have been limited in power capacity and life by wear and other durability/reliability problems.

At present, the most promising CVT designs are those based on chains or belts. Continuing development may well overcome or reduce the significance of their drawbacks relative to the fuel savings possible. These fuel economy improvements could be of the order of 10 percent compared with a conventional automatic transmission—again, depending on the efficiency of the CVT. Fuel economy better than that of a properly driven car with a manual transmission would be more difficult to achieve. Although the CVT would permit the engine to operate more efficiently, poorer transmission efficiency would counterbalance at least some of the savings. One reason that CVTs are expected to have lower efficiencies is the need for a startup device, such as a torque converter, in addition to the CVT mechanism itself. Given that the production costs of a CVT would also be higher than those of a manual design—in part because of the start-up device—CVTs appear most likely to find a place as replacements for conventional automatic transmissions.

The third transmission technology listed in table 5A-1, engine on-off, has been placed in this section only for convenience—it could just as well appear in the engine category. "Engine on-off" systems, by which the powerplant can be automatically shut off during coasting or when stopped at signal lights or in traffic, are in principle easy to implement. Indeed, when current engines are equipped with electronic fuel injection the fuel flow is sometimes cut off when coasting above a predetermined speed. For an engine on-off design to be practical (and safe), the engine must restart quickly and reliably, and the operation of the system should not otherwise affect driveability—i.e., it should be operator-invisible, primarily a matter of control system design. Engine on-off systems are under development, and presumably will be implemented if the production costs prove reasonable compared with the expected fuel savings.

Vehicle Weight

The final group of technologies in table 5A-1—vehicle systems—includes several means of reducing power demand, hence the fuel consumed in moving the car. As discussed in the body of this chapter, the single most important means of reducing fuel consumption is by reducing the weight of the vehicle; a 1-percent decrease in weight typically cuts fuel consumption by 0.7 to 0.8 percent, provided engine size is reduced proportionately. Fuel consumption can also be lessened by reducing air drag, frictional, and parasitic losses—such as accessory demands.

The easiest way to decrease the weight of an automobile is to make it smaller. In most newly designed cars, front-wheel drive is adopted to preserve interior volume, while considerable attention has been given to maximizing space utilization and removing unneeded weight. For cars of a given size, materials with higher strength-to-weight ratios can be used where cost effective, provided they meet requirements for corrosion resistance and stiffness. Progress has also been made by specifying less conservative margins of safety for structural design. Many of the steps taken to reduce vehicle weight interact—i.e., taking weight out of one part of the car, perhaps by replacing 5-mph bumpers with 2-mph bumpers, allows secondary weight savings elsewhere in the body and chassis.

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[43] B. C. Christenson, A. A. Frank, and N. H. Beachley, "The Fuel-Saving Potential of Cars With Continuously Variable Transmissions and an Optimal Control Algorithm," American Society of Mechanical Engineers Paper 75-WA/Aut-20, 1975.

In the future, big gains will be harder to achieve. Most of the waste space has already been taken out of newly designed American cars. Overhangs for styling purposes are being reduced or eliminated, door thicknesses decreased, space utilization in passenger compartments and trunks more carefully planned. Considerable progress can still be made through careful detail design, but the easiest steps are being taken. In the future, tradeoffs between space for passengers and luggage and the weight of the vehicle will be more difficult to manage.

The two basic approaches to reducing weight are: 1) to use materials which provide comparable performance characteristics but weigh less; and 2) to design each component and subsystem with minimum weight as a primary objective—the latter more important now than in the past, when the costs associated with extra testing and analysis were harder to justify through savings in materials and fuel. The first path also tends to raise the manufacturer's costs because substitute materials usually cost more.

Material characteristics most critical in automobile structures are cost, strength, stiffness, and corrosion resistance. Costs—of the material itself, and of the fabrication processes that the choice of material entails—are in the end the controlling factors, as for most mass produced products. Nonstructural parts carry different demands but often less opportunity for saving weight (e.g., upholstery and trim, typically already plastics).

Iron and steel have been the materials of choice for building cars and trucks—as for other mechanical systems—because of their combination of good mechanical properties and low cost. Iron castings have been widely used in engines and powertrain components, steel stampings and forgings in chassis members, bodies, and frames (now often unitized). Highly loaded parts are generally made from heat treated alloy steels—e.g., some internal engine components, as well as gears, bearings, shafts. But elsewhere mild steel has been chosen because it is cheap and easy to fabricate; it can be easily formed and spot welded, gives a good surface finish, and takes paint well. Greater quantities of high-strength, low-alloy steels are now being specified—particularly for bumpers and more critical structural applications such as door guard beams; some new cars contain 200 lb of high-strength steel, triple the amounts of a decade ago.[44] Thinner body parts with good corrosion resistance can be made from galvanized or aluminized sheet steel.

The strength-to-weight ratio of inexpensive, low-strength steels can also be equaled or exceeded by alloys of aluminum and magnesium, as well as by nonmetallic materials such as reinforced plastics. Aluminum usage, now 115 to 120 lb per car, is expected to reach 200 lb per car by 1990—mostly in the form of castings.[45] Aluminum can substitute for iron and steel in engines and transmissions—cylinder heads as well as simpler, less critical components such as housings, covers, and brackets. Magnesium and reinforced plastics are other candidates for some of these applications (use of magnesium is currently limited by high costs, but these may come down in the future). However, aluminum sheet for body parts and structural members has been limited not only by high costs but by difficulty in spot welding—a problem that new alloy compositions are helping overcome.

A variety of plastics and fiber-reinforced composites —ABS, glass-reinforced polyester sheet molding compound, reaction-injection molded polymers with or without reinforcement—are being specified for production parts; some have been used for years. While more of these materials will be used in the future, GM's Corvette—a high-priced specialty vehicle made in quantities small compared with most other domestic vehicles—remains the only mass-produced American car with a glass-reinforced plastic body. Introduced nearly 30 years ago but never emulated, this illustrates the continuing advantages of metals, particularly at high production levels.

In the past, plastics have generally been applied to nonstructural parts. Polymer-matrix composites are now candidates for some structural applications—one 1981 car had a fiberglass rear spring weighing 8 lb, compared with 41 lb for the steel spring it replaced.[46] Examples of related applications, none yet in production, are driveshafts and wheels. Other types of composites—i.e., laminates consisting of two metal layers, probably steel, sandwiching a plastic such as polypropylene—may have potential as body materials. The thickness of the laminate makes it more rigid in bending for a given weight, and the plastic dampens noise and vibration; such laminates, like many other composite materials, are now too costly for widespread use.[47]

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[44] H. E. Chandler, "Useage Update: Light, Longer Lasting Sheet Steels for Autos," *Metal Progress*, October 1981, p. 24.

[45] H. E. Chandler, "A Look Ahead at Auto Materials and Processes in the 80's," *Metal Progress*, May 1980, p. 24.

[46] Ibid.

[47] H. S. Hsia, "Weight Reduction for Light Duty Vehicles, 1980 Summary Source Document" (draft), Department of Transportation, Transportation Systems Center, March 1981, p. 8-31.

Improvements in steels and their applications still offer the greatest scope for near-term weight savings in passenger cars—one reason is that the designer's job becomes more difficult when materials are changed. But the manufacturing problems mentioned above for aluminum as a body material—difficulty in spot welding, forming characteristics that call for changes in die design—at least remain within the realm of conventional, mass production metalworking techniques. Plastics and composites demand processing quite different from that used for metals—and high volume production of structural parts made from such materials is new, not only for the automakers, but for virtually all industries. Furthermore, unconventional materials may need additional engineering analysis and testing—e.g., they are often susceptible to different failure modes (such as environment-induced embrittlement, or discoloring). In fact, the second avenue for weight reduction is precisely an improvement in design methods.

With better methods for analyzing and controlling the stress and deflection in the vehicle structure, weight can be reduced without sacrificing structural integrity. Through better understanding of the failure modes of the materials used, as well as service loadings, margins of safety can be reduced. Both analysis and testing are important to these objectives. The greatest strides have come from widespread adoption by the automobile industry of finite-element methods for structural analysis. Not only can body and chassis structures be designed with more precise control over stresses and deflections—eliminating unnecessary material—but finite-element techniques can also help reduce the weights of engines and other powertrain components; section sizes of engine blocks can be decreased, for example.

The weight reductions, hence fuel economy gains, that are possible through materials substitution are limited primarily by costs—both material cost and manufacturing cost. Graphite reinforcements for polymers perform better than glass, for example, but are considerably more expensive; at the highest strength levels, aluminum alloys, in addition to being expensive and difficult to form, cannot be welded. If the costs justify the benefits in terms of fuel economy and other performance advantages—e.g., corrosion resistance—then automobile designers will choose new materials. In some cases, costs will come down as production volume increases, but there will always be a point of diminishing returns. Nonetheless, continued attention to detail design with conventional materials —with which the automakers have engineering and production experience—and improved methods of structural analysis, can give substantial reductions in weight, as table 5A-1 indicates. Even though downsizing and weight reduction will have proceeded considerably by 1985, improvements will continue—often rather gradually, as manufacturers gain confidence in, and experience with, new materials and improved design methods.

Safety poses a further constraint on the selection of structural materials for automobiles. The tradeoffs between vehicle size and occupant safety are discussed in chapters 5 and 10. For a vehicle of a given size, the mechanical properties of the structural materials are one of the factors on which passenger protection depends. Because the structure needs to be able to absorb large amounts of energy in a collision, the materials should be capable of extensive plastic deformation, or else able to absorb energy by some alternative process such as microfracturing while being crushed. This may limit applications of higher strength materials—both metals and nonmetals—because capacity for plastic deformation is inversely proportional to strength; it may also pose difficult design problems for some composite materials.

Aerodynamic Drag

A lighter automobile needs less power for acceleration and for constant speed travel and therefore consumes less fuel. A car with less aerodynamic drag burns less fuel at any given speed, but the power needed for acceleration is not directly affected. Because drag caused by air resistance is proportional to frontal area and to speed squared, drag reduction helps most at higher speeds—i.e., during highway driving.

Smaller cars have less frontal area, hence less drag. But drag can also be reduced by making a car more "streamlined." This characteristic is quantified by the drag coefficient—which has a value of 1.2 for a flat plate pushed through the air, but only 0.1 for a teardrop shape. For complex geometries such as airplanes or automobiles, drag coefficients can be precisely determined only by experiment. Extensive—and expensive—wind tunnel testing is the basic technique for minimizing the drag coefficient of an automobile.

Theoretical aspects of the aerodynamics of ground vehicles are poorly understood, particularly for shapes as complex as automobile bodies. Interactions between the stationary roadway and the moving car are a particular problem. Drag reductions are sensitive not only to overall vehicle shape—e.g., the sloped frontends now common on passenger cars—but to relatively subtle details—such as integration of the bumpers into the front-end design, and the flow of air through the radiator. Testing and experiment are required before the final form can be chosen.

While typical cars of the early 1970's had drag coefficients in the range of 0.50 to 0.60, many current models have values closer to 0.45, or less; the 1982 Pontiac 6000 has a claimed drag coefficient of 0.37.[48] Reductions to values of less than 0.35 are possible, but eventually limited by practical compromises involving the utility of the vehicle (passenger and luggage space can suffer, as well as accessibility for repairs), safety (a streamlined design may compromise visibility for the driver), and manufacturing costs (curved side glass can cut drag but is more expensive). Even so, by 1990 drag coefficients may average 0.35 or less.[49]

Nonetheless, as table 5A-1 indicates, improvements in fuel economy in the years past 1985 from continuing reductions in aerodynamic drag will be relatively small. The reasons are, first, that considerable progress has already been made, and more can be expected between now and 1985—and the returns from drag reduction rapidly diminish (frontal areas are constrained by the need to fit people into the car; no practical vehicle could approach the lower limit drag coefficient of the teardrop shape)—and, second, that drag reduction has the greatest benefits at high speeds, whereas most driving is done at lower speeds. In general, a 10-percent reduction in drag will yield an improvement in driving-cycle fuel economy of perhaps 2 percent.[50]

Rolling Resistance

Even in the absence of air resistance, some fuel would be burned in pushing a car at a constant speed. This rolling resistance depends on tire characteristics, and on friction and drag in moving parts such as axle bearings. It also depends on the road surface (concrete offers slightly less rolling resistance than asphalt). Most of the resistance is caused by deformation in the tires. Carcass design, tread pattern, and inflation pressure all affect resistance. Radial tires decrease resistance compared with bias-ply carcasses, with fuel-economy improvements of 2 to 5 percent possible;[51] more aggressive tread patterns—e.g., snow tires—increase resistance; higher inflation pressures decrease resistance.

Improved lubricants and bearing designs can also cut resistance slightly, as can brakes with minimal drag. However, more scope for fuel-economy improvements through better lubricants exists elsewhere in the vehicle—particularly in engines, but also in transmissions and rear axles—where more "slippery" oils, as well as design changes that minimize churning and oil spray, can reduce viscous drag. Although decreases in friction and rolling resistance benefit fuel economy at low speeds almost as much as at high, many of the possible gains have already been achieved, or are in sight—thus, further improvements after 1985 will be small (table 5A-1).

Accessories

Some of the power produced by the engine is used, not to move the car or to overcome the engine's internal friction, but in driving pumps, fans, and accessories. To produce this power, fuel must be burned. Among the specific parasitic losses that automobile designers strive to minimize are those associated with cooling fans, air-conditioning compressors, power-steering pumps, and electrical loads supplied by the alternator. Decreases are possible in many of these, as table 5A-1 indicates, though often at somewhat greater cost. In some cases, downsizing the vehicle helps to reduce or eliminate parasitic losses—e.g., power steering may not be needed.

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[48] J. Burton, "82 Pontiac 6000: A Step Further," *Autoweek*, Nov. 30, 1981, p. 10.

[49] D. Scott, "Double Loop Cuts Wind Tunnel Size and Cost," *Automotive Engineering*, May 1981, p. 69.

[50] *Automotive Fuel Economy Program: Fifth Annual Report to the Congress* (Washington, D.C.: Department of Transportation, January 1981), p. 119.

[51] Ibid.

APPENDIX B.—OIL DISPLACEMENT POTENTIAL OF ELECTRIC VEHICLES

Electric Vehicles and Electric Utilities

The extent to which electric vehicle (EV) technology can contribute to the national goal of reducing oil imports will depend on the availability and use of non-petroleum-based electricity for vehicle recharging and the fuel consumption of the car the EV replaces. Because of the limited performance of EVs, they would most likely be substitutes for relatively fuel-efficient small cars. Also, because of the limited range and hauling capacity of EVs, it is assumed that they can replace only 80 percent of the (10,000 miles per year) normal travel in a gasoline car. The remaining 2,000 miles per year would have to be accomplished with a possibly rented gasoline-fueled car, which might be less fuel efficient than the small car that the EV replaced. This latter complication was ignored, however, so the results shown here are slightly more favorable in terms of net oil displacement than might be the case in practice.

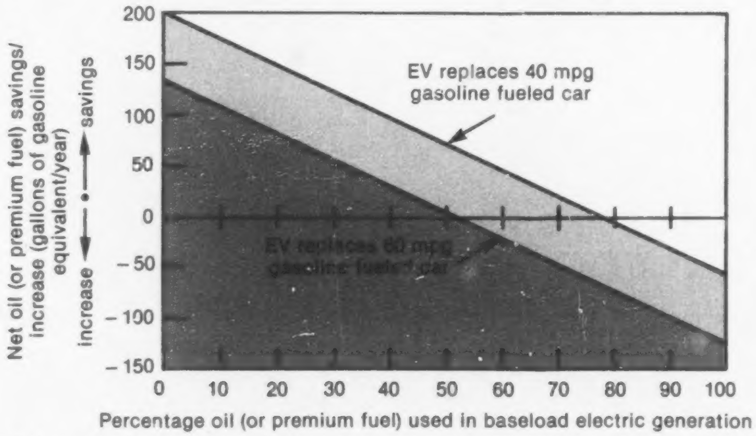
Figure 5B-1 shows the consequences of introducing EVs in terms of either increased petroleum use, or net petroleum savings, for alternative assumptions about automotive fuel economy. For example, referring to the figure, if the fuel economy of the car replaced by an EV is 60 mpg (case A), then one could save as much as 133 gal per year or increase petroleum consumption by 123 gal (of gasoline equivalent) per year depending on whether, respectively, all or none of the recharge electricity is petroleum-based.* As long as the fraction of petroleum used for generating recharge energy for EVs in this case is less than about 50 percent, the introduction of EVs will result in net petroleum savings. In case B, where a car that achieves 40 mpg is replaced by an EV, the fraction of petroleum used for generating recharge energy must be less than about 80 percent to result in net petroleum savings.

Utilities plan their capacity and operations to ensure that the maximum instantaneous demand on the system, typically occurring at midday, can be met. This implies that peakloads are satisfied with generating capacity that is idle at other times. A utility will thus respond to demand fluctuations by using the most efficient ("baseload" as well as "intermediate") plants as much as possible and progressively adding other "peaking" plants as loads increase. Baseload plants, which often cannot be adjusted rapidly (i.e., under 2 hours) to respond to demand fluctuations, are either nuclear, hydro, geothermal, or steam (oil, coal, or gas). Peaking plants can be operated for short-term response and are gas turbines fueled by oil or natural gas and pumped-storage hydro. The ability of utilities to handle the additional load created by EVs will depend on such factors as total generation potential, the equipment and fuel mix, and the time pattern of demands. These characteristics generally vary by region (fig. 5B-2) as illustrated in table 5B-1.

Figure 5B-3 shows a peak summer demand curve and equipment mix for an individual, representative utility. Also shown are the likely changes in the load profile that would occur with the addition of EV loads under the following conditions: 1) recharging occurs over 12 hours during the night when demands on the system are the smallest, 2) recharging occurs uniformly during the day, and 3) recharging occurs during 2 hours at midday. As long as the additional EV load occurs either at night or evenly throughout the day, this load could be accommodated by increasing baseload output. Recharging over 2 hours during the day would be satisfied with peaking plants.

Assuming that the available oil-fueled baseload capacity used for recharging EVs is proportional to the amount of oil-fueled baseload in the system, figure

Figure 5B-1.—Relationship Between the Net Fuel Savings From the Use of EVs and the Fuel Used for Electric Generation



SOURCE: Office of Technology Assessment.

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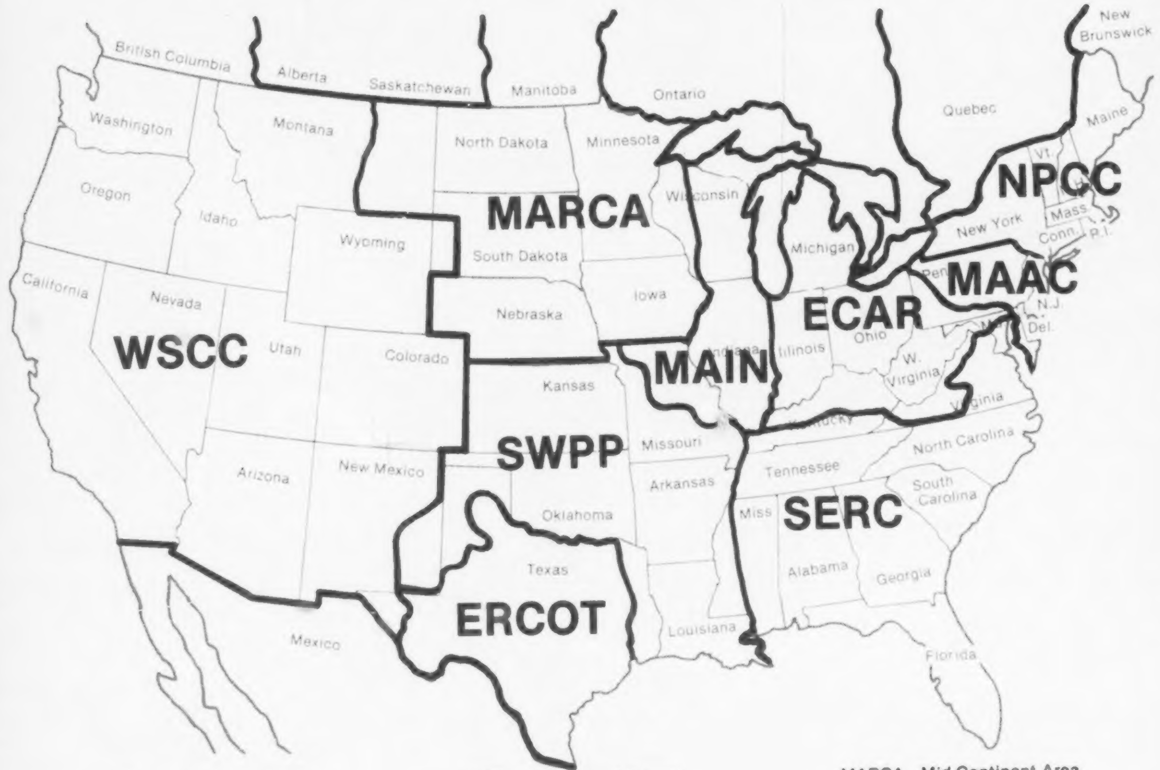
*Assumes that electric vehicle recharge energy is 0.4 kWh/mile.

Figure 5B-2.—Regional Electric Reliability Council Areas


British Columbia
Alberta
Saskatchewan
Manitoba
Ontario
Quebec
New Brunswick
Maine
Washington
Montana
North Dakota
Minnesota
Vt.
NPCC
Oregon
Idaho
MARCA
Wisconsin
Mass.
New York
Conn.
R.I.
Wyoming
South Dakota
Michigan
Penn.
MAAC
California
Nevada
Iowa
Nebraska
ECAR
N.J.
Del.
WSCC
Utah
Colorado
Indiana
Illinois
Ohio
MAIN
W. Virginia
Kansas
Virginia
Kentucky
SWPP
Missouri
North Carolina
Arizona
New Mexico
Tennessee
Arkansas
South Carolina
Oklahoma
Miss
SERC
Texas
Alabama
Georgia
ERCOT
Louisiana
Mexico
Florida

ECAR - East Central Area Reliability Coordination Agreement
MAIN - Mid-America Interpool Network
MAAC - Mid-Atlantic Area Council
SWPP - Southwest Power Pool
ERCOT - Electric Reliability Council of Texas
WSCC - Western Systems Coordinating Council
MARCA - Mid-Continent Area Reliability Coordination Agreement
NPCC - Northeast Power Coordinating Council
SERC - Southeastern Electric Reliability Council

SOURCE: Department of Energy, Energy Information Administration, April 1978.

5B-4 can be used to determine the fuel efficiency that would be required of a small automobile if the overall oil consumption of the small automobile is to be equivalent to an EV in each region. For example, at one extreme, the Texas region uses not oil in its baseload, so an EV always consumes less oil, and at the other extreme, in the northeast a gasoline-fueled car would have to get about 50 mpg if it were to consume an equivalent amount of oil as an EV. In terms of premium fuel,* the extreme points are several hundred mpg in the midcontinent area and about 40 mpg in the Texas region to achieve a fuel-use equivalence between a small car and an EV.

The electricity requirements and oil/premium fuel savings for an EV fleet which constitutes 20 percent* of the total vehicle fleet are shown in table 5B-2. As can be seen, as long as the EV fleet can be recharged using baseload capacity, regions should be able to meet the additional load with existing available baseload capacity. In general, the Northeast, West, and Southeast regions would utilize the greatest absolute amounts of oil-fueled baseload capacity if EVs were

---

*Oil + natural gas = premium fuel.

*A 20-percent market penetration is considered to be the upper bound on EV use through 2010.

Table 5B-1.—Utility Capabilities by Region (contiguous United States)[a]

Region[b]	Installed capacity (×10³ MW)	Net capability (×10³ MW)[c]	Available baseload capacity (×10³ MW)[d]	Available peaking capacity (×10³ MW)[e]	Percent of baseload that is fueled by: Oil	Gas
ECAR	84.9	79.1	19.6	1.3	6.7	0.2
MAAC	44.0	40.6	7.1	2.2	35.3	0.0
MAIN	43.1	39.9	7.6	0.6	12.7	1.1
MARCA	25.4	24.4	5.1	0.8	2.5	0.9
NPCC	50.9	49.8	11.4	2.3	60.4	0.0
SERC	113.7	103.1	17.5	2.6	17.9	0.2
SWPP	48.9	46.1	6.8	0.4	21.6	42.8
ERCOT	40.9	39.9	9.7	0.0	0.0	75.7
WSCC	94.6	93.3	22.0	1.4	26.9	2.3
Total	546.4	516.2	106.8	11.6	20.9	10.8

[a] Unless otherwise indicated, data are taken from the *1980 Summary*, National Electric Reliability Council, July 1980.

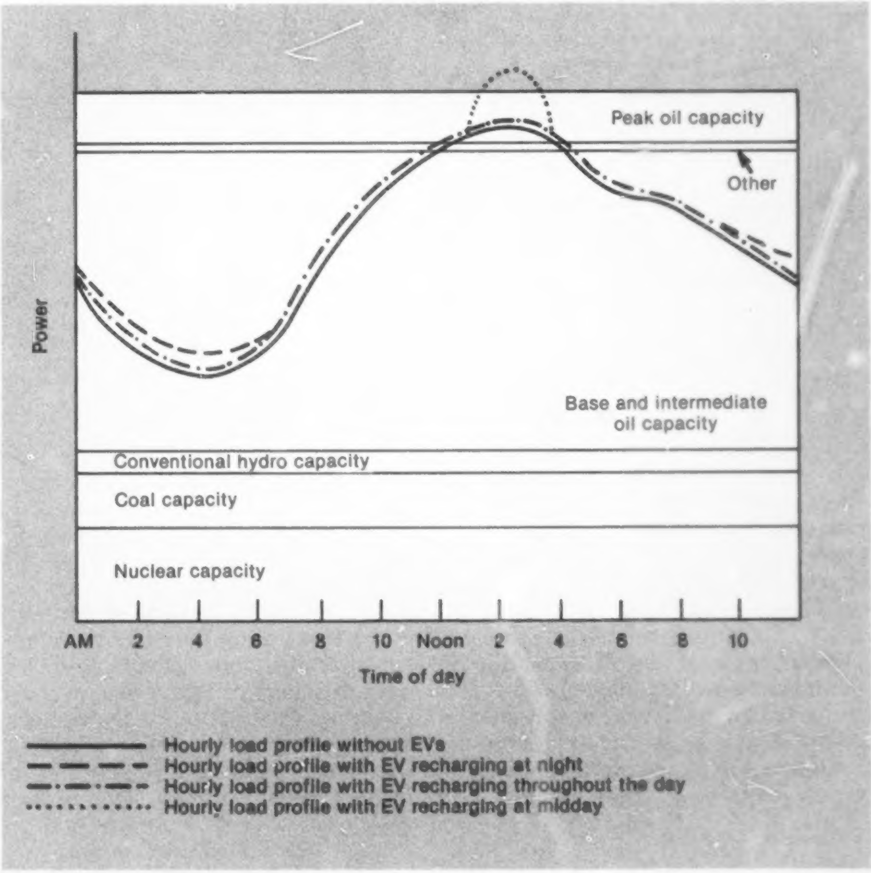
[b] See attached map in fig. 5B-2.

[c] Net capability is calculated based on the ratio of Net Capability to Installed Capacity as reported in the *Electric Power Monthly*, U.S. Department of Energy, Energy Information Administration, August 1980.

[d] Calculations assume that the total available capacity is allocated between baseload and peaking capacity according to the ratio of peaking to baseload capacity within the system. Total available capacity = (net capability) − (peakload).

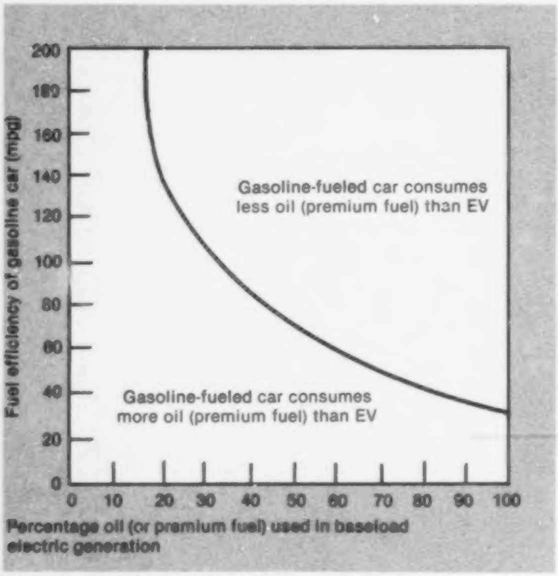
SOURCE: Office of Technology Assessment.

Figure 5B-3.—Illustrative Load Profile With and Without Electric Vehicles



SOURCE: Office of Technology Assessment

Figure 5B-4.—Dependence of Net Oil (premium fuel) Consumption on Efficiency of Gasoline Car Replaced and Fuel Used in Baseload Electric Generation



SOURCE: Office of Technology Assessment.

introduced, whereas the midcontinent, East-Central, and Texas regions would utilize the smallest amounts of oil-fueled baseload capacity.

Petroleum savings accruing from the substitution of EVs (as opposed to 60-mpg gasoline-fueled vehicles) for 20 percent of the total vehicle fleet would be approximately 0.1 MMB/D of oil and 0.07 MMB/D of premium fuel. The greatest oil savings would be in the East-Central, Southeast, and West regions. The smallest amount of oil savings would occur in the Texas, Southwest, and midcontinent regions; substituting EVs for small cars in the Northeast would actually increase oil usage. The greatest premium fuel savings accruing from the substitution of small cars would occur in the East-Central, Southeast, and West regions. Increased premium fuel use would occur in Texas, the Northeast, and the Southwest. In the future, however, both oil and premium fuel savings with EVs will increase as utilities switch away from the use of these fuels for electric generation.

Analyses conducted at the national and regional levels cannot be used to assess the attractiveness of EVs for individual cities or utilities. For example, individual utilities may experience significant increments to their loading, and hence, require a change in baseload capacity and/or mix of fuel use, depending on the time pattern of recharging assumed, the percentage of market penetration, and the technical characteristics of the battery and charging system (e.g., amperage, voltage, and efficiency profiles).

Table 5B-2.—Electricity Requirements and Oil Savings With an Electric Vehicle Fleet With 20-Percent Penetration

Region	Total vehicles 1979[a] (×10⁶)	Electricity capacity required if 20% penetration by EVs[b] as percent of available baseload (percent)			Case A[f] baseload capacity that would be fueled by:		Fuel consumed by fleet of small cars[g] (MMB/DOE)	Fuel saved by replacing 20% of small cars with EVs[h]	
		Case A[c]	Case B[d]	Case C[e]	Oil (MW)	Premium (MW)		Oil saved (MMB/DOE)	Premium fuel saved (MMB/DOE)
ECAR	19.9	0.15	0.07	0.87	194	200	0.191	0.027	0.027
MAIN	9.2	0.19	0.09	1.14	474	474	0.088	0.011	0.010
MAAC	10.9	0.21	0.11	1.26	203	220	0.105	0.005	0.005
MARCA	5.8	0.16	0.08	0.99	21	29	0.056	0.009	0.008
NPCC	14.7	0.19	0.09	1.13	1296	1296	0.141	−0.004	−0.004
SERC	21.2	0.18	0.09	1.06	554	560	0.203	0.021	0.021
SWPP	9.0	0.19	0.10	1.16	284	846	0.087	0.008	−0.003
ERCOT	6.5	0.10	0.05	0.59	0	716	0.063	0.010	−0.005
WSCC	22.6	0.15	0.07	0.90	887	962	0.217	0.017	0.015
Total	119.8	0.16	0.08	0.98	3913	5303	1.151	0.104	0.074

[a] *Ward's Automotive Yearbook 1980*. For each State served by more than one council, vehicles are distributed among the regions according to the percentage of the State's residential consumers served by each council as estimated by the State's public utility commission.

[b] EVs require 0.4 kWh/mile and are driven 8,000 miles per year.

[c] Recharging occurs over 12 hours during the night (1 year = 8,766 hours).

[d] Recharging occurs evenly throughout the day.

[e] Recharging occurs over 2 hours at midday.

[f] Assumes that the fuel used to generate electricity for EVs is in the same percentage as used for baseload generation (see table 5B-1).

[g] Small automobile gets 60 mpg and drives 10,000 miles per year.

[h] EV replaces 80 percent of the miles driven by 20 percent of the cars. Negative sign indicates fuel use increases rather than decreases.

SOURCE: Office of Technology Assessment.

Chapter 6

Synthetic Fuels

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Chapter 6

Synthetic Fuels

INTRODUCTION

Synthetic fuels, or "synfuels," in the broadest sense can include any fuels made by breaking complex compounds into simpler forms or by building simple compounds into others more complex. Both of these types of processes are carried out extensively in many existing oil refineries. Current technical usage, however, tends to restrict the term to liquid and gaseous fuels produced from coal, oil shale, or biomass. This usage will be followed in this report.

Synfuels production is a logical extension of current trends in oil refining. As sources of the most easily refined crude oils are being depleted, refiners are turning to heavier oils and tar sands. Oil shale and coal, as starting materials for liquid hydrocarbon production, are extreme cases of this trend to heavier feedstocks.

Although synfuels production involves several processes not used in crude oil refining, many current oil refining techniques will be applied at various stages of synfuels processing. In order to indicate the range of currently used hydrocarbon processing techniques and to provide definitions of certain terms used later in describing some synfuels processes, a brief description of commonly used oil refining processes is given below. Following this are descriptions of coal, oil shale, and biomass synfuels processes; an evaluation of synfuel economics; and a presentation of two plausible development scenarios for a U.S. synfuels production capacity.

Petroleum Refining

A petroleum refinery is normally designed to process a specific crude oil (or a limited selection of crudes) and to produce a "slate" of products appropriate to the markets being supplied. Refineries vary greatly in size and complexity. At one extreme are small "topping" plants with product outputs essentially limited to the components of the crude being processed. At the other extreme are very large, complex refineries with extensive conversion and treating facilities and a corresponding ability to produce a range of products specifically tailored to changing market needs.

Refining processes include:

- *Atmospheric Distillation.*—The "crude unit" is the start of the refining process. Oil under slight pressure is heated in a furnace and boiled into a column containing trays or packing which serve to separate the various components of the crude oil according to their boiling temperatures. Distillation ("fractionation") is carried out continuously over the height of the column. At several points along the column hydrocarbon streams of specific boiling ranges are withdrawn for further processing.
- *Vacuum Distillation.*—Some crude oil components have boiling points that are too high, or they are too heat-sensitive, to permit distillation at atmospheric pressure. In such cases the so-called "topped crude" (bottoms from the atmospheric column) is further distilled in a column operating under a vacuum. This lowers the boiling temperature of the material and thereby allows distillation without excessive decomposition.
- *Desulfurization.*—Sulfur occurs in crude oil in various amounts, and in forms ranging from the simple compound hydrogen sulfide and mercaptans to complex ring compounds. The sulfur content of crude oil fractions increases with boiling point. Thus, although sulfur compounds in fractions with low boiling points can readily be removed or rendered unobjectionable, removal becomes progressively more difficult and expensive with fractions of higher boiling points. With these materials, sulfur is removed by processing with hydrogen in the presence of special catalysts at elevated temperatures and pressures. The "hydrofining," "hydrodesulfurization," "residuum hydrotreating," and "hydrodemetallation" processes are examples. Nitrogen compounds

and other undesirable components are also removed in many of these hydrotreating processes.

- *Thermal Cracking Processes.*—Prior to the development of fluid catalytic cracking (see below), the products of distillation that were heavier than gasoline were commonly "cracked" under high temperature and pressure to break down these large, heavy molecules into smaller, more volatile ones and thereby improve gasoline yields. Although the original process is no longer applied for this purpose, two other thermal cracking processes are being increasingly used. In *visbreaking,* highly viscous residues from crude oils are mildly cracked to produce fuel oils of lower viscosity. In *delayed coking,* crude unit residues are heated to high temperatures in large drums and severely cracked to drive off the remaining high-boiling materials for recovery and further processing; the porous mass of coke left in the drums is used as a solid fuel or to produce electric furnace electrodes.
- *Fluid Catalytic Cracking.*—This process in its various forms is one of the most widely used of all refinery conversion techniques. It is also undergoing constant development. Charge stocks (which can be a range of distillates and heavier petroleum fractions) are entrained in a hot, moving catalyst and converted to lighter products, including high-octane gasoline. The catalyst is separated and regenerated, while the reaction products are separated into their various components by distillation.
- *Hydrocracking.*—This process converts a wide range of hydrocarbons to lighter, cleaner, and more valuable products. By catalytically adding hydrogen under very high pressure, the process increases the ratio of hydrogen to carbon in the feed and produces low-boiling material. Under some conditions hydrocracking may be competitive with fluid catalytic cracking.
- *Catalytic Reforming.*—Reforming is a catalytic process that takes low-octane "straight-run" materials and raises the octane number to approximately 100. Although several chemical reactions take place, the predominant reaction is the removal of hydrogen from naphthenes (hydrogen-saturated ring-like compounds) and their conversion to aromatics (benzene-ring compounds). In addition to markedly increasing octane number, the process produces hydrogen that can be used in desulfurization units.
- *Isomerization, Catalytic Polymerization, and Alkylation.*—These are specialized processes that increase refinery yields of high-octane gasoline blending components from selected straight-chain liquids and certain refinery gases.

Historically, the U.S. refining industry has dealt primarily with light, low-sulfur crudes. Using processes described above, the industry achieved a balance between refinery output and markets. Adjustments have been made to meet the increasing demand for lead-free gasolines and to the mandated reduction of lead in other gasolines. The heavy residual fuels, considerably higher in sulfur content than treated distillate fuels, have continued to find a market as ships' boilers and as fuels for utility plants that have not converted to coal. (In the latter market, it has sometimes been necessary to blend in desulfurized fuel oils to meet maximum fuel sulfur specifications.) In addition, large volumes of residual fuel oils have continued to be imported, largely from Venezuela and the Caribbean.

Now, however, the picture is changing. Due to the limited availability of light crude oils, refineries are being forced to run increasing volumes of heavy crudes that are higher in sulfur and other contaminants. With traditional processing methods, these crudes produce fewer light products and more heavy fuel oils of high sulfur content. On the other hand, fuel switching and conservation in stationary uses will shift market demand increasingly toward transportation fuels—gasoline, diesel, and jet—plus petrochemical feedstock.

Refiners are responding to this situation by making major additions to processing facilities. Although they differ in detail, the additions are intended to reduce greatly the production of heavy fuel oil and to maximize the conversion and recovery of light liquids. For a typical major refinery, the additions could include: 1) vacuum distillation facilities, 2) high-severity hydroprocessing, such as residuum desulfurization, together with hydrogen manufacturing capacity, 3) delayed coking, along with processes to recover and treat the high-boiling vapor fractions driven off, and 4) perhaps visbreaking, catalytic cracker expansions, and other modifications to accommodate the changed product slate. It should also be noted that none of these additions increases the crude-processing capacity of a refinery; they merely adapt it to changed supply and marketing conditions.

Purvin and Gurtz[1] have estimated the costs of upgrading domestic refining capacity to make such changes. Their results are shown in table 40. Although, as indicated in note *d* of the table, the investments shown do not include all applicable costs, upgrading existing refineries is, in most cases, less expensive than building synfuels plants to produce the same products; and there are regular reports that investments are being made in oil refineries to upgrade residual oil and change the product slate.*[2]

For a discussion of other issues related to oil refineries, the reader is referred to a Congressional Research Service report on "U.S. Refineries: A Background Study."[3]

Table 40.—Analysis of Potential for Upgrading Domestic Refining Capacity

	Topping refineries		Total U.S. refineries
	Case 1a[a]	Case 1b[b]	Case 2[c]
Total investment[d]	$2.3 billion	$4.7 billion	$18.0 billion
Reduction in total U.S. residual fuel production, bbl/d	217,000-301,000	418,000-501,000	1,587,000-1,670,000
Percent total pool	13-18	25-30	95-100
Increase in motor gasoline production, bbl/d	134,000-200,000	167,000-234,000	467,000-534,000
Percent total pool	2-3	2.5-3.5	7-8
Increase in diesel/No. 2 fuel production, bbl/d	105,000-135,000	150,000-180,000	540,000-600,000
Percent total pool	3.5-4.5	5-6	18-20
Increase in low-Btu gas, MMBtu/D	—	233	1,320
Implementation period, years	2-3	3-4	4-10
Investment per unit capacity	$6,800-9,600 per bbl/d	$11,300-14,000 per bbl/d	$15,800-17,900 per bbl/d

[a] Vacuum distillation, catalytic cradking, visbreaking.
[b] Vacuum distillation, catalytic cracking, coking plus gasification.
[c] Case 1b plus coking and gasification and downstream upgrading at remaining U.S. refineries.
[d] First-quarter 1980 investment. No provision for escalation, contingency or interest during construction.

SOURCE: Purvin & Gertz, Inc., "An Analysis of Potential for Upgrading Domestic Refining Capacity," prepared for American Gas Association, 1980.

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[1] Purvin & Gertz, Inc., "An Analysis of Potential for Upgrading Domestic Refining Capacity," prepared for American Gas Association, Arlington, Va., undated.

*Another issue related to refining and oil consumption is the low yield of lubrication and specialty oils from certain types of crude oils (paraffinic crudes) and the rerefining or reuse of these oils. There appears to be no technical problem with increasing the yield of lubrication and specialty oils from the paraffinic crudes (*Oil and Gas Journal*, "Gulf's Port Arthur Refinery Due More Upgrading," Sept. 8, 1980, p. 36.) or the rerefining of lubrication oils. However, heat transfer, hydraulic, capacitor, and transformer fluids often become contaminated with PCBs (polychlorinated biphenyls) leached from certain plastics such as electrical insulating materials. Because of the health hazard, EPA regulations limit the allowable level of PCBs in enclosed systems to 50 ppm (parts per million). The contaminated oils pose a waste disposal problem and could damage refinery equipment (through the formation of corrosive hydrogen chloride and possible catalyst poisoning) if rerefined without treatment. Recently, however, two processes (*Chemical and Engineering News*, "Goodyear Develops PCB Removal Method," Sept. 1, 1980, p. 9; *Chemical and Engineering News*, "More PCB Destruction Methods Developed," Sept. 22, 1980, p. 6.) have been announced that enable the removal of most of the PCBs, thereby enabling reuse directly or rerefining if necessary; and one of these processes has been demonstrated with a prototype commercial unit. Consequently, there do not appear to be significant technical problems with decontamination and reuse of PCB-contaminated oils. Due to the limits of this study, however, OTA was unable to perform an economic analysis of oil production from paraffinic crudes, rerefining of lubrication oils, or decontamination of specialty oils.

[2] For example, *Oil and Gas Journal*, Aug. 25, 1980, p. 69; *Oil and Gas Journal*, Sept. 8, 1980, p. 36; *Oil and Gas Journal*, Nov. 10, 1980, p. 150; *Oil and Gas Journal*, Jan. 19, 1981, p. 85.

[3] Congressional Research Service, "U.S. Refineries: A Background Study," prepared at the request of the Subcommittee on Energy and Power of the House Committee on Interstate and Foreign Commerce, U.S. House of Representatives, July 1980.

PROCESS DESCRIPTIONS

A variety of synthetic fuels processes are currently being planned or are under development. Those considered here involve the chemical synthesis of liquid or gaseous fuels from solid materials. As mentioned above, the impetus for synthesizing fluid fuels is to provide fuels that can easily be transported, stored, and handled so as to facilitate their substitution for imported oil and, to a lesser extent, imported natural gas.

The major products of various synfuels processes are summarized in table 41. Depending on the processes chosen, the products of synfuels from coal include methanol (a high-octane gasoline substitute) and most of the fuels derived from oil* and natural gas. The principal products from upgrading and refining shale oil are similar to those obtained from conventional crude-oil refining. The principal biomass synfuels are either methanol or a low- to medium-energy fuel gas. Smaller amounts of ethanol (an octane-boosting additive to gasoline or a high-octane substitute for gasoline) and biogas can also be produced. Each of these fuels can be synthesized further into any of the other products, but these are the most easily produced from each source and thus probably the most economic.

In the following section, the technologies for producing synfuels from coal, oil shale, and biomass are briefly described. Indirect and direct coal liquefaction and coal gasification are presented first. Shale oil processes are described second, followed by various biomass synfuels. Hydrogen and acetylene production are not included because a preliminary analysis indicated they are likely to be more expensive and less convenient transportation fuels than are the synthetic liquids.[4]

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*As with natural crude oil, however, refining to produce large gasoline fractions usually requires more refining energy and expense than producing less refined products such as fuel oil.

[4] For a more detailed description of various processes, see: Engineering Societies Commission on Energy, Inc., "Coal Conversion Comparison," July 1979, Washington, D.C.; *An Assessment of Oil Shale Technologies* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1980), OTA-M-118; *Energy From Biological Processes* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, July 1980), vol. I, OTA-E-124; and *Energy From Biological Processes, Volume II—Technical and Environmental Analyses* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, September 1980), OTA-E-128.

Table 41.—Principal Synfuels Products

Process	Fuel production	Comments
Oil shale	Gasoline, diesel and jet fuel, fuel oil, liquefied petroleum gases (LPG)	Shale oil is the synfuel most nearly like natural crude.
Fischer-Tropsch	Gasoline, synthetic natural gas (SNG), diesel fuel, and LPG	Process details can be modified to produce principally gasoline, but at lower efficiency.
Coal to methanol, Mobil methanol to gasoline (MTG)	Gasoline and LPG	LPG can be further processed to gasoline. Some processes would also produced considerable SNG.
Coal to methanol	Methanol	Depending on gasifier, SNG may be a byproduct. Methanol most useful as high-octane gasoline substitute or gas turbine fuel, but can also be used as gasoline octane booster (with cosolvents), boiler fuel, process heat fuel, and diesel fuel supplement. Methanol can also be converted to gasoline via the Mobil MTG process.
Wood or plant herbage to methanol	Methanol	Product same as above.
Direct coal liquefaction	Gasoline blending stock, fuel oil or jet fuel, and LPG	Depending on extent of refining, product can be 90 volume percent gasoline.
Grain or sugar to ethanol	Ethanol	Product most useful as octane-boosting additive to gasoline, but can serve same uses as methanol.
SNG	SNG	Product is essentially indistinguishable from natural gas.
Coal to medium- or low-energy gas	Medium- or low-energy fuel gas	Most common product likely to be close to synthesis gas.
Wood or plant herbate gasification	Medium- or low-energy fuel gas	Fuel gas likely to be synthesized at place where it is used.
Anaerobic digestion	Biogas (carbon dioxide and methane) and SNG	Most products likely to be used onsite where produced.

SOURCE: Office of Technology Assessment.

Synfuels From Coal

Liquid and gaseous fuels can be synthesized by chemically combining coal with varying amounts of hydrogen and oxygen,* as described below. The coal liquefaction processes are generally categorized according to whether liquids are produced from the products of coal gasification (indirect processes) or by reacting hydrogen with solid coal (direct processes). The fuel gases from coal considered here are medium-Btu gas and a synthetic natural gas (SNG or high-Btu gas). Each of these three categories is considered below and shown schematically in figure 13.

Indirect Liquefaction

The first step in the indirect liquefaction processes is to produce a synthesis gas consisting of carbon monoxide and hydrogen and smaller quantities of various other compounds by reacting coal with oxygen and steam in a reaction vessel called a gasifier. The liquid fuels are produced

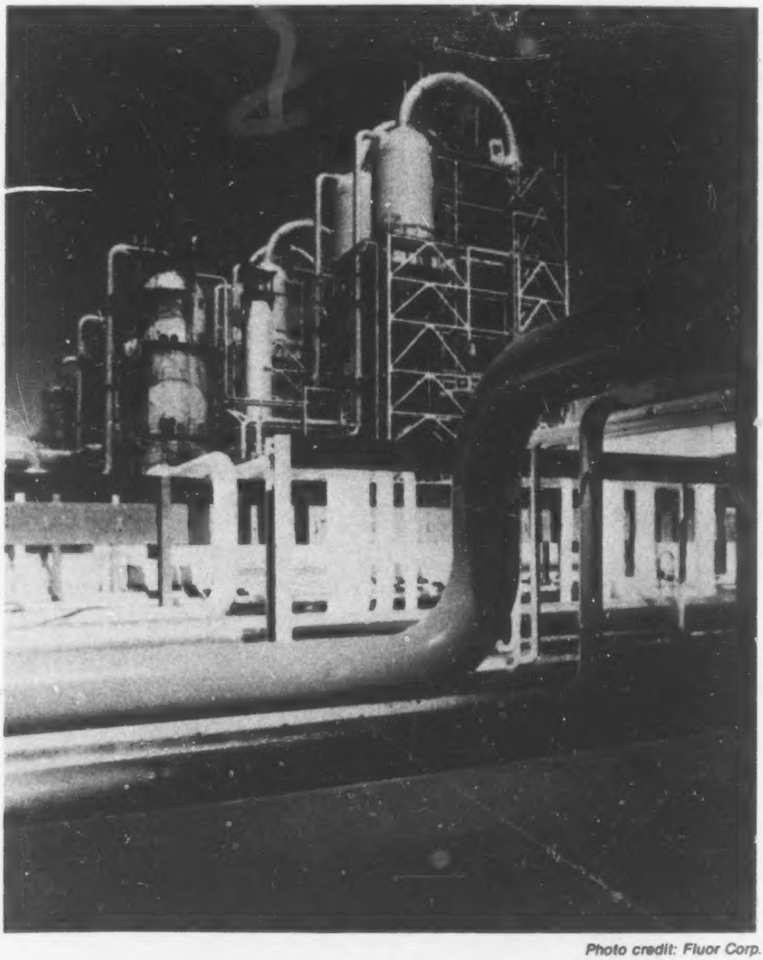

Photo credit: Fluor Corp.

Synthesis gas is converted to liquid hydrocarbons in Fischer-Tropsch type reactors

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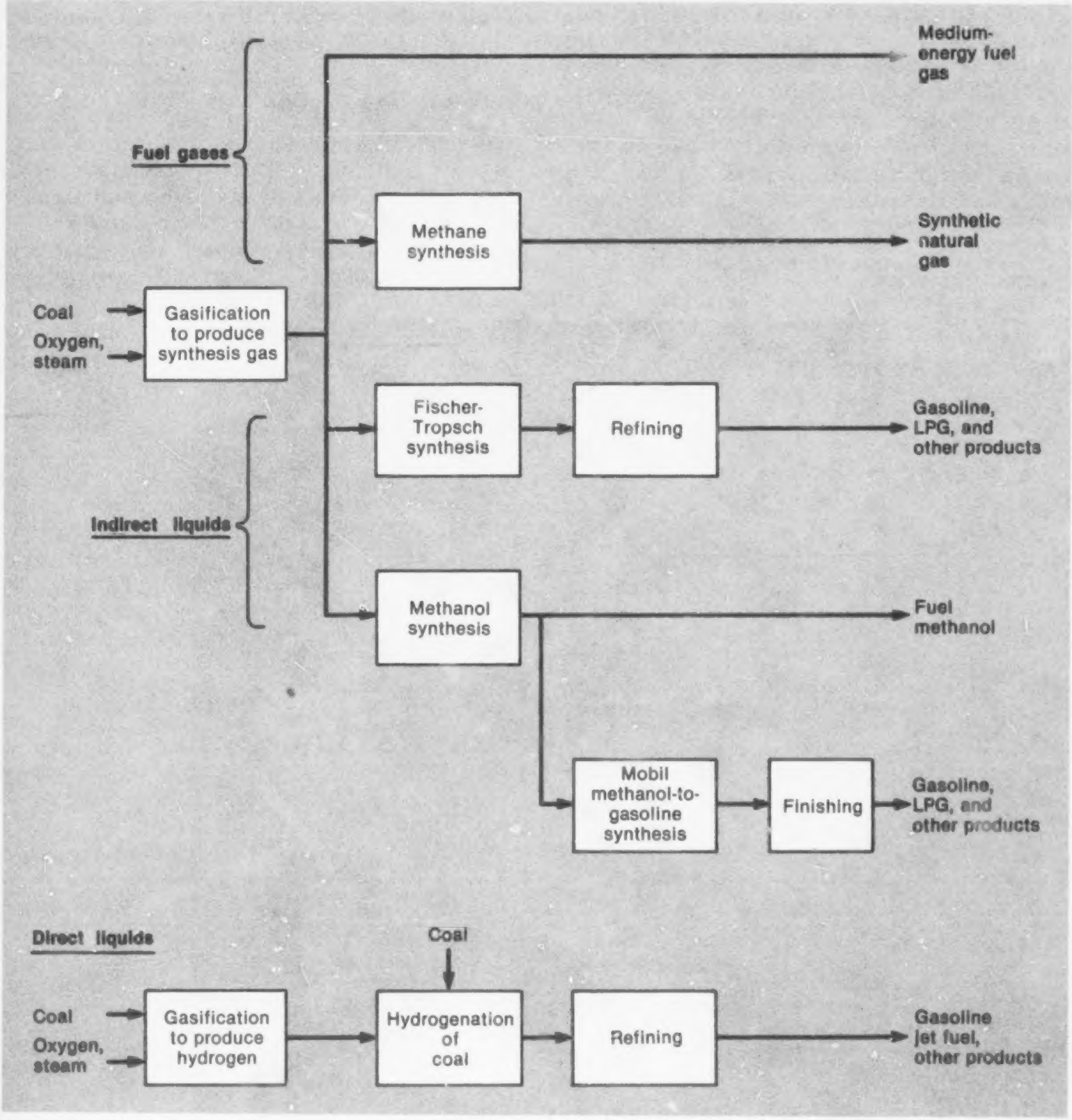
*Some liquid and gaseous fuel can be obtained simply by heating coal, due to coal's small natural hydrogen content, but the yield is low.

Figure 13.—Schematic Diagrams of Processes for Producing Various Synfuels From Coal


Fuel gases
Medium-energy fuel gas
Methane synthesis
Synthetic natural gas
Coal
Oxygen, steam
Gasification to produce synthesis gas
Fischer-Tropsch synthesis
Refining
Gasoline, LPG, and other products
Indirect liquids
Methanol synthesis
Fuel methanol
Mobil methanol-to-gasoline synthesis
Finishing
Gasoline, LPG, and other products
Direct liquids
Coal
Coal
Oxygen, steam
Gasification to produce hydrogen
Hydrogenation of coal
Refining
Gasoline jet fuel, other products

SOURCE: Office of Technology Assessment.

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by cleaning the gas, adjusting the ratio of carbon monoxide to hydrogen in the gas, and pressurizing it in the presence of a catalyst. Depending on the catalyst, the principal product can be gasoline (as in the Fischer-Tropsch process) or methanol. The methanol can be used as a fuel or further reacted in the Mobil methanol-to-gasoline (MTG) process (with a zeolite catalyst) to produce Mobil MTG gasoline. The composition of the gasoline and the quantities of other products produced in the Fischer-Tropsch process can also be adjusted by varying the temperature and pressure to which the synthesis gas is subjected when liquefied.

With commercially available gasifiers, part of the synthesis gas is methane, which can be purified and sold as a byproduct of the methanol or gasoline synthesis.* However, the presence of methane in the synthesis gas increases the energy needed to produce the liquid fuels, because it must be pressurized together with the synthesis gas but does not react to form liquid products. Alternatively, rather than recycling purge gas (containing increasing concentrations of methane) to the methanol synthesis unit, it can be sent to a methane synthesis unit and its carbon monoxide and hydrogen content converted to SNG. With "second generation" gasifiers (see below), little methane would be produced and the methanol or gasoline synthesis would result in relatively few byproducts.

There are three large-scale gasifiers with commercially proven operation: Lurgi, Koppers-Totzek, and Winkler. Contrary to some reports in the literature, all of these gasifiers can utilize a wide range of both Eastern and Western coals,** although Lurgi has not been commercially proven with Eastern coals. In all cases, the physical properties of the feed coal will influence the exact design and operating conditions chosen* for a gasifier. For example, the coal swelling index, ease of pulverization (friability), and water content are particularly important parameters to the operation of Lurgi gasifiers, and the Koppers-Totzek gasifier requires that the ash in the coal melt for proper operation, as do the Shell and Texaco "second generation" designs.

It is expected that the developing pressurized, entrained-flow Texaco and Shell gasifiers will be superior to existing commercial gasifiers in their ability to handle strongly caking Eastern coals with a rapid throughput. This is achieved by rapid reaction at high temperatures (above the ash melting point). These temperatures, however, are achieved at the cost of reduced thermal efficiency and increased carbon dioxide production.

The Fischer-Tropsch process is commercial in South Africa, using a Lurgi gasifier, but the United States lacks the operating experience of South Africa and it is unclear whether this will pose problems for commercial operation of this process in the United States. The methanol synthesis from synthesis gas is commercial in the United States, but a risk is involved with putting together a modern coal gasifier with the methanol synthesis, since these units have not previously been operated together. Somewhat more risk is involved with the Mobil MTG process, since it has only been demonstrated at a pilot plant level. Nevertheless, since the Mobil MTG process involves only fluid streams** the process can probably be brought to commercial-scale operation with little technical difficulty.

Direct Liquefaction

The direct liquefaction processes produce a liquid hydrocarbon by reacting hydrogen directly with coal, rather than from a coal-derived synthesis gas. However, the hydrogen probably will be produced by reacting part of the coal with steam to produce a hydrogen-rich synthesis gas, so these processes do not eliminate the need for coal gasification. The major differences between the processes are the methods used to transfer the hydrogen to the coal, while maximizing catalyst life and avoiding the flow problems associated with bringing solid coal into contact with a solid catalyst, but the hydrocarbon products are likely to be quite similar. The three major direct liquefaction processes are described briefly below, followed by a discussion of the liquid product and the state of the technologies' development.

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*For example, the synthesis gas might typically contain 13 percent methane. Following methanol synthesis, the exiting gases might contain 60 percent methane, which is sufficiently concentrated for economic recovery.

**For example, Sharman (R. B. Sharman, "The British Gas/Lurgi Slagging Gasifier—What It Can Do," presented at Coal Technology '80, Houston, Tex., Nov. 18-20, 1980) states: "It has been claimed that the fixed bed gasifiers do not work well with swelling coals. Statements such as this can still be seen in the literature and are not true. In postwar years Lurgi has given much attention to the problem of stirrer design which has much benefited the Westfield Slagging Gasifier. Substantial quantities of strongly caking and swelling coals such as Pittsburgh 8 and Ohio 9, as well as the equivalent strongly caking British coals have been gasified. No appreciable performance difference has been noted between weakly caking and strongly caking high volatile bituminous coals."

*Including steam and oxygen requirements.

**The physical behavior of fluids is fairly well understood, and processes involving only fluid streams can be scaled up much more rapidly with minimum risk than processes involving solids.

The solvent-refined coal (SRC I) process was originally developed to convert high-sulfur, high-ash coals into low-sulfur and low-ash solid fuels. Modifications in the process resulted in SRC II, which produces primarily a liquid product. The coal is slurried with part of the liquid hydrocarbon product and reacted with hydrogen at about 850° F and a pressure of 2,000 per square inch (psi).[5] As it now stands, however, feed coal for this process is limited to coals containing pyritic minerals which act as catalysts for the chemical reactions.

The H-coal process involves slurrying the feed coal with part of the product hydrocarbon and reacting it with hydrogen at about 650° to 700° F and about 3,000 psi pressure in the presence of a cobalt molybdenum catalyst.[6] A novel aspect of this process is the so-called "ebullated" bed reactor, in which the slurry's upward flow through the reactor maintains the catalyst particles in a fluidized state. This enables contact between the coal, hydrogen, and catalyst with a relatively small risk of clogging.

The third major direct liquefaction method is the EXXON Donor Solvent (EDS) process. In this process, hydrogen is chemically added to a solvent in the presence of a catalyst. The solvent is then circulated to the coal at about 800° F and 1,500 to 2,000 psi pressure.[7] The solvent then, in chemical jargon, chemically donates the hydrogen atoms to the coal; and the solvent is recycled for further addition of hydrogen. This process circumvents the problems of rapid catalyst deactivation and excessive hydrogen consumption.

In all three processes, the product is removed by distilling it from the slurry, so there is no residual oil* fraction in these "syncrudes." Because of the chemical structure of coal, the product is high in aromatic content. The initial product is unstable and requires further treatment to produce a stable fuel. Refining** the "syncrude" consists of further hydrogenation or coking (to increase hydrogen content and remove impurities), cracking, and reforming; and current indications are that the most economically attractive product slate consists of gasoline blending stock and fuel oil,[8] but it is possible, with somewhat higher processing costs, to produce products that vary from 27 percent gasoline and 61 percent jet fuel up to 91 percent gasoline and no jet fuel.[9]

The gasoline blending stock is high in aromatics, which makes it suitable for blending with lower octane gasoline to produce a high-octane gasoline. Indications are that the jet fuel can be made to meet all of the refinery specifications for petroleum-derived jet fuel.[10] However, since the methods used to characterize crude oils and the products of oil refining do not uniquely determine their chemical composition, the refined products from syncrudes will have to be tested in various end uses to determine their compatibility with existing uses. Because of the chemistry involved, these syncrudes appear economically less suitable for the production of diesel fuel.***

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[5] Engineering Societies Commission on Energy, Inc., op. cit.

[6] Cameron Engineering, Inc., "Synthetic Fuels Data Handbook," 2d ed., compiled by G. L. Baughman, 1978.

[7] Ibid.

*Residual oil is the fraction that does not vaporize under distillation conditions. Since this syncrude is itself the byproduct of distillation, all of the fractions vaporize under distillation conditions.

**At present, it is not clear whether existing refineries will be modified to accept coal syncrudes or refineries dedicated to this feedstock will be built. Local economics may dictate a combination of these two strategies. Refining difficulty is sometimes compared to that of refining sour Middle East crude when no high-sulfur residual fuel oil product is produced (i.e., refining completely to middle distillates and gasoline) (see footnote 8). This is moderately difficult but well within current technical capabilities. One of the principal differences between refining syncrudes and natural crude oil, however, is the need to deal with different types of metallic impurities in the feedstock.

[8] UOP, Inc., and System Development Corp., "Crude Oil vs. Coal Oil Processing Comparsion Study," DOE/ET/03117, TR-80/009-001, November 1979.

[9] Chevron, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes, Third Interim Report: Processing of SRC II Syncrude," FE-2135-47, under DOE contract No. EF-76-C-01-2315, Apr. 30, 1981.

[10] Ibid.

***The product is hydrogenated and cracked to form saturated, single-ring compounds, and to saturated diolefins (which would tend to form char at high temperatures). The reforming step pro-

None of the direct liquefaction processes has been tested in a commercial-scale plant. All involve the handling of coal slurries, which are highly abrasive and have flow properties that cannot be predicted adequately with existing theories and experience. Consequently, engineers cannot predict accurately the design requirements of a commercial-scale plant and the scale-up must go through several steps with probable process design changes at each step. As a result, the direct liquefaction processes are not likely to make a significant contribution to synfuels production before the 1990's. At this stage there would be a substantial risk in attempting to commercialize the direct liquefaction processes without additional testing and demonstration.

Gasification

The same type of gasifiers used for the liquefaction processes can be used for the production of synthetic fuel gases. The first step is the production of a synthesis gas (300 to 350 Btu/SCF).* The synthesis gas can be used as a boiler fuel or for process heat with minor modifications in end-use equipment, and it also can be used as a chemical feedstock. Because of its relatively low energy density and consequent high transport costs, synthesis gas probably will not be transported (in pipelines) more than 100 to 200 miles. There is very little technical risk in this process, however, since commercial gasifiers could be used.

The synthesis gas can also be used to synthesize methane (the principal component of natural gas having a heat content of about 1,000 Btu/SCF). This substitute or synthetic natural gas (SNG) can be fed directly into existing natural gas pipelines and is essentially identical to natural gas. There is some technical risk with this process, since the methane synthesis has not been demonstrated at a commercial scale. However, since it only involves fluid streams, it probably can be scaled up to commercial-scale operations without serious technical difficulties.

As mentioned under "Indirect Liquefaction," there are several commercial gasifiers capable of producing the synthesis gas. The principal technical problems in commercial SNG projects are likely to center around integration of the gasifier and methane synthesis process.

Shale Oil

Oil shale consists of a porous sandstone that is embedded with a heavy hydrocarbon (known as kerogen). Because the kerogen already contains hydrogen, a liquid shale oil can be produced from the oil shale simply by heating the shale to break (crack) the kerogen down into smaller molecules. This can be accomplished either with a surface reactor, a modified in situ process, or a so-called true in situ process.

In the surface retorting method, oil shale is mined and placed in a metal reactor where it is heated to produce the oil. In the "modified in situ" process, an underground cavern is excavated and an explosive charge detonated to fill the cavern with broken shale "rubble." Part of the shale is ignited to produce the heat needed to crack the kerogen. Liquid shale oil flows to the bottom of the cavern and is pumped to the surface. In the "true in situ" process, holes are bored into the shale and explosive charges ignited in a particular sequence to break up the shale. The "rubble" is then ignited underground, producing the heat needed to convert the kerogens to shale oil.

The surface retort method is best suited to thick shale seams near the surface. The modified in situ is used where there are thick shale seams deep underground. And the true in situ method is best suited to thin shale seams near the surface. The surface retorting method requires the mining and disposal of larger volumes of shale than the modified in situ method and the true in situ method requires only negligible mining. It is more difficult, using the latter two processes, however, to achieve high oil yields of a relatively uniform quality, primarily because of difficulties related to controlling the underground combustion and

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duces aromatics from the saturated rings. The rings can also be broken to form paraffins, but the resultant molecules and other paraffins in the "oil" are too small to have a high cetane rating (the cetane rating of one such diesel was 39 (see footnote 9), while petroleum diesels generally have a centane of 45 or more (E. M. Shelton, "Diesel Fuel Oils, 1980," DOE/BETC/PPS-80/5, 1980)). Polymerization of the short chains into longer ones to produce a high-cetane diesel fuel is probably too expensive.

**Assuming the gas consists primarily of carbon monoxide and hydrogen.

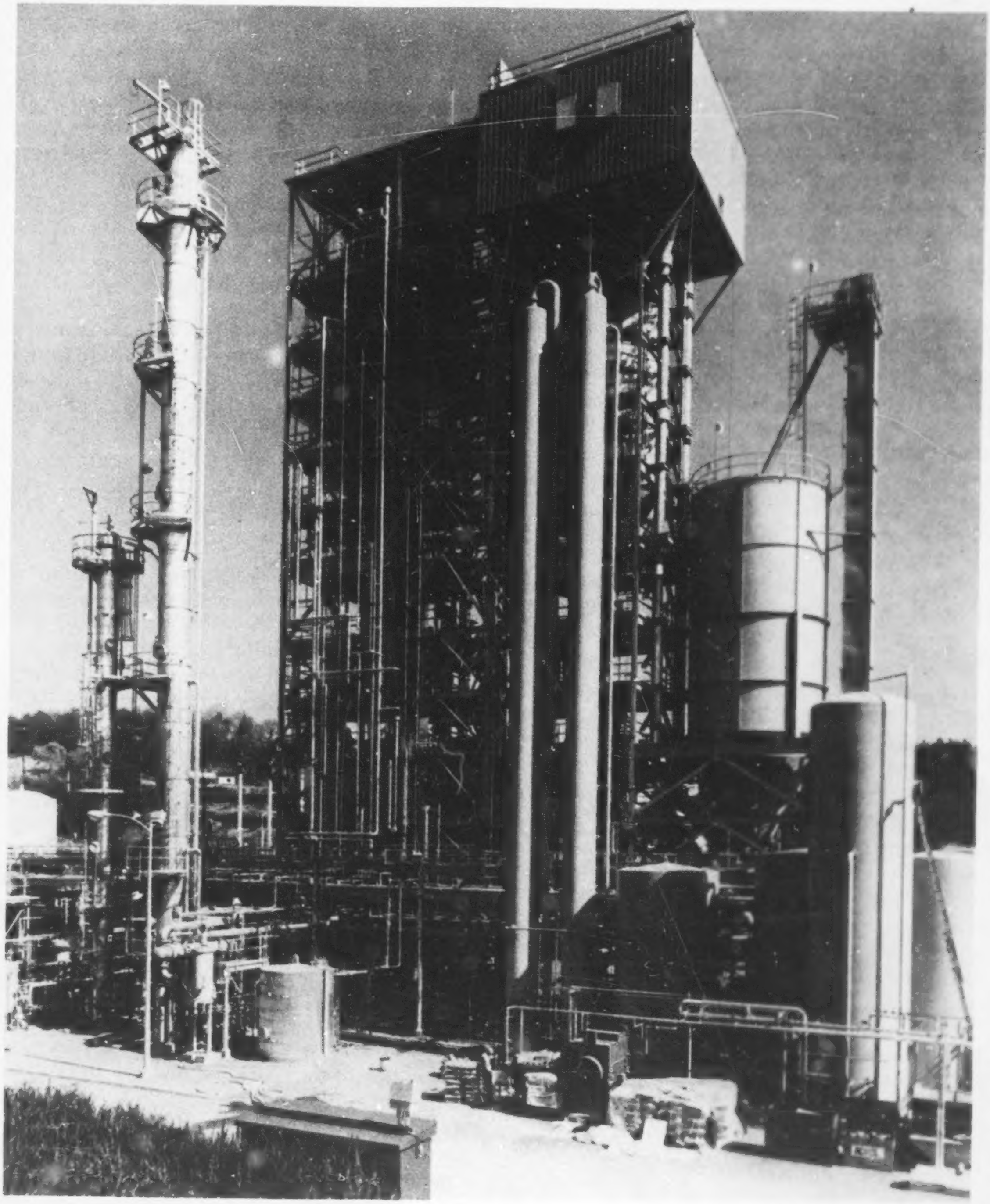

Photo credit: Department of Energy

Synthane pilot plant near Pittsburgh, Pa., converts coal to synthetic natural gas ensuring that the resultant heat is efficiently transferred to the shale. It is likely, however, that these problems can be overcome with further development work.

The shale oil must be hydrogenated under conditions similar to coal hydrogenation (800° F, 2,000 psi)[11] to remove its tightly bound nitrogen, which, if present, would poison refinery catalysts.

The resultant upgraded shale oil is often compared to Wyoming sweet crude oil in terms of its refining characteristics and is more easily refined than many types of higher sulfur crude oils currently being refined in the United States. Refining shale oil naturally produces a high fraction of diesel fuel, jet fuel, and other middle distillates. The products, however, are not identical to the fuels from conventional crude oil, so they must be tested for the various end uses.

Shale oil production is currently moving to commercial-scale operation, and commercial facilities are likely to be in operation by the mid to late 1980's. Because of completed and ongoing development work, the risks associated with moving to commercial-scale operation at this time are probably manageable, although risks are never negligible when commercializing processes for handling solid feedstocks.

Synthetic Fuels From Biomass

The major sources of biomass energy are wood and plant herbage, from which both liquid and gaseous fuels can be synthesized. These syntheses and the production of some other synfuels from less abundant biomass sources are described briefly below.

Liquid Fuels

The two liquid fuels from biomass considered here are methanol ("wood alcohol") and ethanol ("grain alcohol"). Other liquid fuels from biomass such as oil-bearing crops must be considered as speculative at this time.[12]

Methanol can be synthesized from wood and plant herbage in essentially the same way as it is produced from coal. One partially oxidizes or simply heats (pyrolyzes) the biomass to produce a synthesis gas. The gas is cleaned, the ratio of carbon monoxide to hydrogen adjusted, and the resultant gas pressurized in the presence of a catalyst to form methanol. As with the indirect coal processes, the synthesis gas could also be converted to a Fischer-Tropsch gasoline or the methanol converted to Mobil MTG gasoline.

Methanol probably can be produced from wood with existing technology, but methanol-from-grass processes need to be demonstrated. Several biomass gasifiers are currently under development to improve efficiency and reliability and reduce tar and oil formation. Particularly notable are pyrolysis gasifiers which could significantly increase the yield of methanol per ton of biomass feedstock. Also mass production of small (5 million to 10 million gal/yr), prefabricated methanol plants may reduce costs significantly. With adequate development support, advanced gasifiers and possibly prefabricated methanol plants could be commercially available by the mid to late 1980's.

Ethanol production from grains and sugar crops is commercial technology in the United States. The starch fractions of the grains are reduced to sugar or the sugar in sugar crops is used directly. The sugar is then fermented to ethanol and the ethanol removed from the fermentation broth by distillation.

The sugar used for ethanol fermentation can also be derived from the cellulosic fractions of wood and plant herbage. Commercial processes for doing this use acid hydrolysis technology, but are considerably more expensive than grain-based processes. Several processes using enzymatic hydrolysis and advanced pretreatments of wood and plant herbage are currently under development and could produce processes which synthesize ethanol at costs comparable to those of ethanol derived from grain, but there are still significant economic uncertainties.[13]

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[11] Chevron, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes, First Interim Report: Paraho Shale Oil," Report HCP/T2315-25 UC90D, Department of Energy, July 1978.

[12] *Energy From Biological Processes*, op. cit.

[13] Ibid.

Fuel Gases

By 2000, the principal fuel gases from biomass are likely to be a low-energy gas from airblown gasifiers and biogas from manure. Other sources may include methane (SNG) from the anaerobic digestion of municipal solid waste and possibly kelp.

A relatively low-energy fuel gas (about 200 Btu/SCF) can be produced by partially burning wood or plant herbage with air in an airblown gasifier. The resultant gas can be used to fuel retrofitted oil- or gas-fired boilers or for process heat needs. Because its low energy content economically prohibits long-distance transportation of the gas, most users will operate the gasifier at the place where the fuel gas is used. Several airblown biomass gasifiers are under development, and commercial units could be available within 5 years.

Biogas (a mixture of carbon dioxide and methane) is produced when animal manure or some types of plant matter are exposed to the appropriate bacteria in an anaerobic digester (a tank sealed from the air). Some of this gas (e.g., from the manure produced at large feedlots) may be purified, by removing the carbon dioxide, and introduced into natural gas pipelines, but most of it is likely to be used to generate electricity and provide heat at farms where manure is produced. The total quantity of electricity produced this way would be small and, to an increasing extent, would be used to displace nuclear- and coal-generated electricity. A part of the waste heat from the electric generation can be used for hot water and space heating in buildings on the farm, however.[14] A small part of the biogas (perhaps 15 percent corresponding to the amount occurring on large feedlots) could be purified to SNG and introduced into natural gas pipelines.

Biogas can also be produced by anaerobic digestion of municipal solid waste in landfills and kelps. Any gas so produced is likely to be purified and introduced into natural gas pipelines.

Manure digesters for cattle manure are commercially available. Digesters utilizing other manures require additional development, but could be commercially available within 5 years. The technology for anaerobic digestion of municipal solid waste was not analyzed, but one system is being demonstrated in Florida.[15] In addition, if ocean kelp farms prove to be technically and economically feasible, there may be a small contribution by 2000 from the anaerobic digestion of kelp to produce methane (SNG),[16] but this source should be considered speculative at present.

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[14] TRW, "Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990," March 1980.

[15] I. E., Associates, "Biological Production of Gas," contractor report to OTA, April 1979, available in *Energy From Biological Processes, Vol III: Appendixes, Part C,* September 1980.

[16] *Energy From Biological Processes,* op. cit.

COST OF SYNTHETIC FUELS

There is a great deal of uncertainty in estimating costs for synthetic fuels plants. A number of factors, which can be predicted with varying degrees of accuracy, contribute to this uncertainty. Some of the more important are considered below, followed by estimates for the costs of various synfuels.

Uncertainties

For most of the synfuels, fixed charges are a large part of the product costs. Depending on assumptions about financing, interest rates, and the required rate of return on investment, these charges can vary by more than a factor of 2. In many cases, differences in product cost estimates can be explained solely on the basis of these differences. For most of the biomass fuels, the cost of the biomass feedstock is also highly variable, and this has a strong influence on the product cost.

The cost of synfuels projects, and particularly the very large fossil fuel ones, is also affected by: 1) construction delays, 2) real construction cost increases (corrected for general inflation) during construction, and 3) delays in reaching full production capacity after construction is completed, due to technical difficulties. These factors are usually not included in cost estimates, but they are likely to affect the product cost.

Another factor that should be considered is the state of development of the technology on which the investment and operating cost estimates are based. As technology development proceeds, problems are discovered and solved at a cost, and the engineer's original concept of the plant is gradually replaced with a closer and closer approximation of how the plant actually will look. Consequently, calculations based on less developed technologies are less accurate. This usually means that early estimates understate the true costs by larger margins than those based on more developed and well-defined technologies. This is particularly true of processes using solid feedstocks because of the inherent difficulty with scaling-up process streams involving solids. Figure 14 illustrates cost escalations that can occur, by summarizing the increases in cost estimates for various energy projects as technology development proceeded. Table 42 also illustrates this point by showing average cost overruns that have occurred in various types of large construction projects.

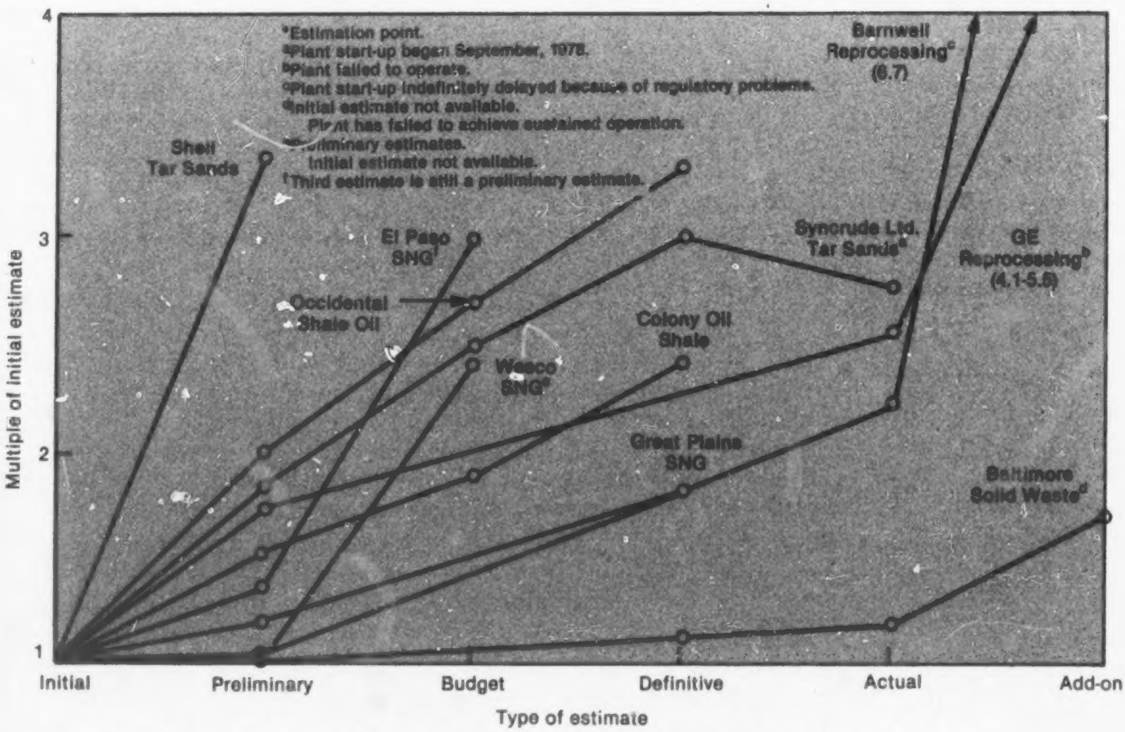
It should be noted, however, that the period of time in which most of the project evaluations

Table 42.—Average Cost Overruns for Various Types of Large Construction Projects

System type	Actual cost divided by estimated cost
Weapons systems	1.40-1.89
Public works	1.26-2.14
Major construction	2.18
Energy process plants	2.53

SOURCES: Rand Corp., "A Review of Cost Estimates in New Technologies: Implications for Energy Process Plants," prepared for U.S. Department of Energy, July 1979; Hufschmidt and Gerin, "Systematic Errors in Cost Estimates for Public Investment Projects," in *The Analysis of Public Output*. Columbia University Press, 1970; and R. Perry, et al., "Systems Acquisition Strategies," Rand Corp., 1970.

Figure 14.—Cost Growth in Pioneer Energy Process Plants (constant dollars)



*Estimation point.
[a]Plant start-up began September, 1978.
[b]Plant failed to operate.
[c]Plant start-up indefinitely delayed because of regulatory problems.
[d]Initial estimate not available.
Plant has failed to achieve sustained operation.
Preliminary estimates.
Initial estimate not available.
[f]Third estimate is still a preliminary estimate.

SOURCE: "A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants," Rand Corp. R-2481- DOE, July 1979.

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in table 42 were made had high escalation rates for capital investment relative to general economic inflation. Historically this has not been the case; and if future inflation in plant construction more nearly follows general inflation, the expected synfuels investment increases from preliminary design to actual construction would be lower than is indicated in figure 14 and table 42.

When judging the future costs and economic competitiveness of synfuels, one must therefore also consider the long-term inflation in construction costs. To a very large extent, the ability to produce synfuels at costs below those of petroleum products will depend on the relative inflation rates of crude oil prices and construction costs.

Although economies of scale are important for synfuels plants, there are also certain diseconomies of scale—factors which tend to increase construction costs (per unit of plant capacity) for very large facilities as compared with small ones. First, the logistics of coordinating construction workers and the timely delivery of construction materials become increasingly difficult as the construction project increases in size and complexity. Second, construction labor costs are higher in large projects due to overtime, travel, and subsistence payments. Third, as synfuels plants increase in size, more and more of the equipment must be field-erected rather than prefabricated in a factory. This can increase the cost of equipment, although in some cases components may be "mass-produced" on site, thereby equaling the cost savings due to prefabrications. Some of these problems causing diseconomies of scale can be aggravated if a large number of synfuels projects are undertaken simultaneously.

Many of the above factors would tend to increase costs, but once several full-scale plants have been built, the experience gained may help reduce production costs for future generations of plants. Delays in reaching full production capacity can be minimized, and process innovations that reduce costs can be introduced. In addition, very large plants that fully utilize the available economies of scale can be built with confidence. Consequently, the first generation units produced are likely to be the most expensive, if adjustments are made for inflation in construction and operating costs.

An example of this can be found in the chemical industry, where capital productivity (output per unit capital investment) for the entire industry has increased by about 1.4 percent per year since 1949.[17] In some sectors, such as methanol synthesis, productivity has increased by more than 4 percent per year for over 20 years.[18] Much of this improvement is attributable to increased plant size and the resultant economies of scale. Because the proposed synfuels plants are already relatively large, cost decreases for synfuels plants may not be as large and consistent as those experienced in the chemical industry in recent years; however, because of the newness of the industry, some decreases are expected.

Investment Cost

For purposes of cost calculations, previous OTA estimates[19] [20] were used for oil shale and biomass synfuels (adjusted, in the case of oil shale, to 1980 dollars) and the best available cost estimates in the public literature were used for coal-derived synfuels. These latter estimates were compared[21] to the results of an earlier Engineering Societies' Commission on Energy (ESCOE) study[22] of coal-derived synfuels, which used preliminary engineering data. Since the best available cost estimates correspond roughly to definitive engineering estimates, the ESCOE numbers were increased by 50 percent, the amount by which engineering estimates typically increase when going from preliminary to definitive estimates. When these adjustments were made and the costs expressed in 1980 dollars, the two sources of cost estimates for coal-based synfuels produced roughly comparable results.[23]

Table 43 shows the processes and product slates used for the cost calculations. As described above, a variety of alternative product slates are possible, but these were chosen to emphasize the production of transportation fuels. Table 44 gives the best available investment and operating costs

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[17] E. J. Bentz & Associates, Inc., "Selected Technical and Economic Comparisons of Synfuel Options," contractor report to OTA, 1981.

[18] Ibid.

[19] *An Assessment of Oil Shale Technologies,* op. cit.

[20] *Energy From Biological Processes,* op. cit.

[21] E. J. Bentz & Associates, Inc., op. cit.

[22] Engineering Societies Commission on Energy, Inc., op. cit.

[23] E. J. Bentz & Associates, Inc., op. cit.

Table 43.—Selected Synfuels Processes and Products and Their Efficiencies

		Energy efficiency[a] (percent)	
Process	Fuel products (percent of output)	Fuel products (percent of input coal and external power)	Tranportation fuel products (percent of input coal and external power)
Oil shale	Gasoline (19)[b] Jet fuel (22) Diesel fuel (59)	N.A.[c]	N.A.[c]
Methanol/synthetic natural gas (SNG) from coal	Methanol (48)[d] SNG (49) Other (3)	65	33
Methanol from coal	Methanol (100)[e f]	55[g]	55[g]
Coal to methanol/SNG, Mobil methanol to gasoline	Gasoline (40)[d] SNG (52) Other (8)	63	27
Coal to methanol, Mobil methanol to gasoline	Gasoline (87)[d] Other (13)	47	41
Fischer-Tropsch/SNG from coal	Gasoline (33)[d] SNG (65) Other (2)	56	17
Direct coal liquefaction	Gasoline (33)[f h] Jet fuel (49) Other (18)	57	47
SNG from coal	SNG (100)[f]	59	0
Methanol from wood	Methanol (100)[i]	47[f]	47[h]
Ethanol from grain	Ethanol (100)[i]	N.A.[c]	N.A.[c]

[a] Higher heating value of products divided by higher heating value of the coal plus imported energy.

[b] R. F. Sullivan, et al., "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," first interim report, prepared by Chevron for Department of Energy, April 1978, NTIS No. FE-2315-25.

[c] Not applicable.

[d] Max Schreiner, "Research Guidance Studies to Assess Gasoline From Coal to Methanol-to-Gasoline and Sasol-Type Fischer-Tropsch Technologies," prepared by Mobil R&D Co. for the Department of Energy, August 1978, NTIS No. FE-2447-13.

[e] DHR, Inc., "Phase I Methanol Use Options Study," prepared for the Department of Energy under contract No. DE-AC01-79PE-70027, Dec. 23, 1980.

[f] K. A. Rogers, "Coal Conversion Comparisons," Engineering Societies Commission on Energy, Washington, D.C., prepared for the Department of Energy, July 1979, No. FE-2468-51.

[g] Sullivant and Frumking (footnote h) give 57 percent, DHR (footnote e) gives 52 percent.

[h] R. F. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels by Advanced Catalytic Processes," third interim report, prepared by Chevron for the Department of Energy, Apr. 30, 1980, NTIS, No. FE-2315,47. Products shown are for H-Coal. It is assumed that same product slate results from refined EDS liquids.

[i] OTA, *Energy From Biological Processes, Volume II*, September 1980, GPO stock No. 052-003-00782-7.

SOURCE: Office of Technology Assessment.

(excluding coal costs) in 1980 dollars for the various processes, with all results normalized to the production of 50,000 barrels per day (bbl/d) oil equivalent of product to the end user (i.e., including refining losses). Only a generic direct liquefaction process is included because current estimation errors appear likely to be greater than any differences between the various direct liquefaction processes.

Based on the history of cost escalation in the construction of chemical plants, one can be nearly certain that final costs of the first generation of these synfuels plants will exceed those shown in table 44 (with the exception of ethanol which is already commercial). Using a methodology developed to estimate this cost escalation, Rand Corp. has examined several synfuels processes and derived cost growth factors, or estimates of how much the capital investment in the synfuels plant is likely to exceed the best available engineering estimates. Some of the results of the Rand study are shown in table 45. Also shown is the expected performance of each plant if it were built today, expressed as the percentage of designed fuel production that the plant is likely to achieve.

The figures reflect Rand's judgment that direct liquefaction processes require further development before construction of a commercial-scale plant should be attempted; but the calculations also indicate that even the first generation of near-commercial processes are likely to be more ex-

Table 44.—Best Available Capital and Operating Cost Estimates for Synfuels Plants Producing 50,000 bbl/d Oil Equivalent of Fuel to End Users

Process	Capital investment (billion 1980 dollars)	Annual operating costs (exclusive of coal costs) (million 1980 dollars)
Oil shale[a]	$2.2	$250
Methanol/SNG from coal[b]	2.1	150
Methanol from coal[c]	2.8	200
Coal to methanol/SNG, Mobil methanol to gasoline[b]	2.4	170
Coal to methanol, Mobil methanol to gasoline[b]	3.3	230
Fischer-Tropsch/SNG from coal[b]	2.5	190
Direct coal liquefaction[d]	3.0	250
SNG[e]	2.2	150
Methanol from wood[f]	2.9	610 (wood at $30/dry ton) 790 (wood at $45/dry ton)
Ethanol[f]	1.8	860 ($3/bu. corn) 1,112 ($4.50/bu. corn)

[a] Office of Technology Assessment, *An Assessment of Oil Shale Technologies*, June 1980, $1.7 billion investment in 1979 dollars becomes $1.9 billion in 1980 dollars for 50,000 bbl/d of shale oil. Assuming 88 percent refining efficiency, one needs 57,000 bbl/d of shale oil to produce 50,000 bbl/d oil equivalent of products, at an investment of $1.9 billion/0.88 = $2.2 billion.

[b] Derived from R. M. Wham, et al., "Liquefaction Technology Assessment—Phase 1: Indirect Liquefaction of Coal to Methanol and Gasoline Using Available Technology," Oak Ridge National Laboratory, ORNL-5664, February 1981.

[c] From DHR, Inc., "Phase I Methanol Use Options Study," prepared for the Department of Energy under contract No. DE-AC01-79PE-70027, Dec. 23, 1980, one finds that the ratio of investment cost of a methanol to a Mobil methanol-to-gasoline plant is 0.85. Assuming this ratio and the value for a methanol-to-gasoline plant from footnote b, one arrives at the investment cost shown. The operating cost was increased in proportion to investment cost. This adjustment is necessary to put the costs on a common basis. These values are 50 percent more than the estimates given by DHR (reference above) and Badger (Badger Plants, Inc., "Conceptual Design of a Coal to Methanol Commercial Plant," prepared for the Department of Energy, February 1978, NTIS No. FE-2416-24). In order to compare Badger with this estimate, it was necessary to scale down the Badger plant (using a 0.7 scaling factor) and inflate the result to 1980 dollars (increase by 39 percent from 1977).

[d] Exxon Research and Engineering Co., "EDS Coal Liquefaction Process Development, Phase V," prepared for the Department of Energy under cooperative agreement DE-FC01-77ET10069, March 1981. Investment and operating cost assumes an energy efficiency of 82.5 percent for the refining process. Refinery investment of up to $700 million is not included in the capital investment.

[e] Rand Corp., "Cost and Performance Expectations for Pioneer Synthetic Fuels Plants," report No. R-2571-DOE, 1981.

[f] Office of Technology Assessment, *Energy From Biological Processes, Volume II*, September 1980, GPO stock No. 052-003-00782-7; i.e., 40 million gallons per year methanol plant costing $88 million, 50 million gallons per year ethanol plant costing $75 million.

SOURCE: Office of Technology Assessment.

Table 45.—Estimates of Cost Escalation in First Generation Synfuels Plants

Process	Cost growth factor derived by Rand[a] for 90 percent confidence interval[b]	Revised investment cost (billion 1980 dollars)	Expected performance for 90 percent confidence interval[b] (percent of plant design)
Oil shale	1.04-1.39	2.3-3.1	57-85
Coal to methanol to gasoline (Mobil, no SNG byproduct)	1.06-1.43	3.5-4.7	65-93
Direct coal liquefaction (H-Coal)	1.52-2.38[a]	4.0-6.3[a]	25-53
SNG	0.95-1.23	2.1-2.7	69-97

[a] Based on Rand study in which best estimate for H-Coal is $2.2 billion for 50,000 bbl/d of product syncrude. With 82.5 percent refining efficiency, this becomes $2.7 billion for 50,000 bbl/d of product to end user.

[b] In other words, 90 percent probability that actual cost growth factor or performance will fall in the interval.

SOURCE: Office of Technology Assessment; adapted from Rand Corp., "Cost and Performance Expectations for Pioneer Synthetic Fuels Plants," R-2571-DOE, 1981.

pensive and less reliable than the best conventional engineering estimates would indicate. This analysis indicates that it is quite reasonable to expect first generation coal liquefaction plants of this size to cost $3 billion to $5 billion or more each in 1980 dollars.

Consumer Cost

The consumer costs of the various synfuels are shown in table 46. These consumer costs are based on the estimates in table 44 and the economic assumptions listed in table 47. The effect on the calculated product cost of varying some of the economic assumptions is then shown in table 48.

With these economic assumptions, delivered liquid fossil synfuels costs (1980 dollars) range from $1.25 to $1.85 per gallon of gasoline equivalent (gge) for 100 percent equity financing and $0.80 to $1.25/gge with 75 percent debt financing at 5 percent real interest (i.e., relative to inflation). In 1981 dollars, these estimates become $1.40 to 2.10/gge and $0.90 to $1.40/gge, respectively. This compares with a reference cost of gasoline from $32/bbl crude oil of $1.20/gal (plus $0.17/gal taxes).

Extreme caution should be exercised when interpreting these figures, however. They represent the best current estimates of what fossil synfuels will cost after technical uncertainties have been resolved through commercial demonstration. They do not include any significant cost increases that may occur from design changes, hyperinflation in construction costs, or construction delays. They most likely represent a lower limit for the synfuels costs.

Table 46.—Consumer Cost of Various Synthetic Transportation Fuels

	100% equity financing, 10% real return on investment			25% equity/75% debt financing, 10% real return on investment		
	Plant or refinery gate product cost	Delivered consumer cost of fuel[a]		Plant or refinery gate product cost	Delivered consumer cost of fuel[a]	
Process	1980 dollars per barrel oil equivalent (5.9 MMBtu/B)	1980 dollars per gallon gasoline equivalent (125 k Btu/gal)	1980 $/MMBtu	1980 dollars per barrel oil equivalent (5.9 MMBtu/B)	1980 dollars per gallon gasoline equivalent (125 k Btu/gal)	1980 $/MMBtu
Reference cost of gasoline from $32/bbl crude oil . .	47	1.20	9.50	47	1.20	9.50
Oil shale	52[b]	1.30	10.40	33[b]	0.90	7.20
Methanol/SNG from coal . .	43	1.30[c d]	10.60[c]	25	0.95[c d]	7.50[c]
Methanol from coal	58	1.60[d]	13.00	33	1.10[d]	8.80
Coal to methanol/SNG, Mobil methanol to gasoline	49[e]	1.25[c d]	10.00[c]	29[e]	0.80[c d]	6.40[c]
Coal to methanol, Mobil methanol to gasoline . . .	67[e]	1.60[d]	12.90	38[e]	1.00[d]	8.10
Fischer-Tropsch/SNG from coal	52[e]	1.30[c]	10.40[c]	30[e]	0.85[c]	6.70[c]
Direct coal liquefaction . . .	77[f]	1.85	14.60	51[f]	1.25	10.20
SNG from coal	45	1.15[g]	9.10[g]	26	0.75[g]	5.90[g]
Methanol from wood	68 (79)[h]	1.85 (2.05)[h]	14.70 (16.60)[h]	49 (60)[h]	1.45 (1.70)[h]	11.60 (13.40)[h]
Ethanol from grain	71 (87)[i]	1.80 (2.15)[i]	14.50 (17.10)[i]	60 (75)[i]	1.55 (1.90)[i]	12.60 (15.10)[i]

[a] Assuming $0.20/physical gallon delivery charge and mark-up; fuel taxes not included.

[b] Includes $6/bbl refining cost. Derived from R. F. Sullivan, et al., "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," first interim report by Chevron Research Corp. to the Department of Energy, April 1978, by increasing cost of $4.50/bbl by 22 percent to reflect 1980 dollars and adjusting for 88 percent refinery efficiency.

[c] Assumes coproduct SNG selling for same price per MMBtu at the plant gate as the liquid product.

[d] Although the plant or refinery gate cost of methanol is lower than MTG gasoline, the delivered consumer cost of methanol is higher due to the higher cost of delivering a given amount of energy in the form of methanol as compared with gasoline, because of the lower energy content per gallon of the former.

[e] All necessary refining is included in the conversion plant.

[f] Includes $14/bbl refining cost from R. F. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes, Third Interim Report," report to the Department of Energy, Apr. 30, 1980, NTIS No. FE-2315-47. Refining costs for EDS and H-Coal are assumed to be the same as SRC II. Note, however, that refining costs drop to $10/bbl for production of heating oil and gasoline and increase to $16.50/bbl for production of gasoline only.

[g] $1.49/MMBtu delivery charge and markup, which corresponds to the 1980 difference between the wellhead and residential price of natural gas. Energy Information Administration, U.S. Department of Energy, "1980 Annual Report to Congress," vol. 2, DOE/EIA-0173 (80)/2, pp. 117 and 119.

[h] Assumes $30/dry ton wood. Number in parentheses corresponds to $45/dry ton wood.

[i] Assumes $3/bu. corn. Number in parentheses corresponds to $4.50/bu. corn.

SOURCE: Office of Technology Assessment.

Table 47.—Assumptions

1. Project life—25 years following 5-year construction period for fossil synfuels and 2-year construction period for biomass synfuels.
2. 10 year straight-line depreciation.
3. Local taxes and property insurance as in K. K. Rogers, "Coal Conversion Comparisons," ESCOE, prepared for U.S. Department of Energy under contract No. EF-77-C-01-2468, July 1979.
4. 10 percent real rate of return on equity investment with: 1) 100 percent equity financing, and 2) 75 percent debt/25 percent equity financing with 5 percent real interest rate.
5. 90 percent capacity or "onstream factor."
6. Coal costs $30/ton delivered to synfuels plant (1980 dollars).
7. 46 percent Federal and 9 percent State tax.
8. Working capital = 10 percent of capital investment.

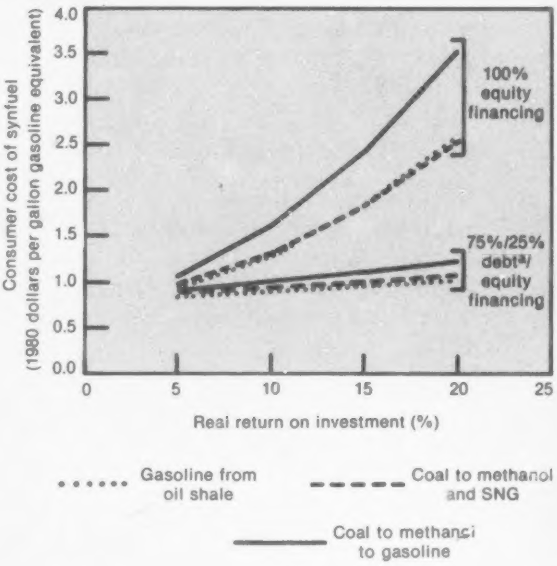
SOURCE: Office of Technology Assessment.

Table 48.—Effect of Varying Financial Parameters and Assumptions on Synfuels' Costs

Change	Effect on synfuels cost
Plant operates at a 50 percent on stream factor rather than 90 percent	Increase 60-70%
Increase capital investment by 50 percent	Increase 15-35%
8-year construction rather than 5-year	Increase 5-20%
Increase coal price by $15/ton	Increase $5-7/bbl

SOURCE: Office of Technology Assessment.

Figure 15.—Consumer Cost of Selected Synfuels With Various Aftertax Rates of Return on Investment



[a] 5% real interest rate on debt.

SOURCE: Office of Technology Assessment.

Because cost overruns and poor plant performance lower the return on investment, investors in the first round of synfuels plants are likely to require a high calculated rate of return on investment to ensure against these eventualities. Put another way, anticipated cost increases (table 45) would lead investors to require higher product prices than those in table 46 before investing in synfuels.

The effects on product costs of various rates of return on investment are shown in figure 15 for selected processes, and the effect of changes in various other economic parameters is shown in table 48. As can be seen, product costs could vary by more than a factor of 2 depending on the technical, economic, and financial conditions that pertain.

Nevertheless, it can be concluded that factors which reduce the equity investment and the required return on that investment and those which help to ensure reliable plant performance are the most significant in holding synfuels costs down. These factors do not always act unambiguously, however. Inflation during construction, for example, increases cost overruns, but inflation after construction increases the real (deflated) return on investment. The net effect is that the synfuels cost more than expected when plant production first starts, but continued inflation causes the prices of competing fuels to rise and consequently allows synfuels prices—and returns on investment —to rise as well. Similarly, easing of environmental control requirements can reduce the time and investment required to construct a plant, but inadequate controls or knowledge of the environmental impacts may lead to costly retrofits which may perform less reliably than alternative, less polluting plant designs.

Another important factor influencing the cost of some synthetic transportation fuels is the price of coproduct SNG. In table 46 it was assumed that any coproduct SNG would sell for the same price per million Btu (MMBtu) at the plant gate as the liquid fuel products, or from $4 to $9/

MMBtu, which compares with current wellhead prices of up to $9/MMBtu[24] for some decontrolled gas. (These prices are averaged with much larger quantities of cheaper gas, so average consumer prices are currently about $3 to $5/MMBtu.) However, the highest wellhead prices may not be sustainable in the future as their "cushion" of cheaper gas gets smaller, causing averge consumer prices to rise. This is because consumer prices are limited by competition between gas and competing fuels—e.g., residual oil—and probably cannot go much higher without causing many industrial gas users to switch fuels. Large quantities of unconventional natural gas might be produced at wellhead prices of about $10 to $11/MMBtu,[25] so SNG coproduct prices are unlikely to exceed this latter value in the next two decades. If the SNG coproduct can be sold for only $4/MMBtu or less, synfuels plants that do not produce significant quantities of SNG will likely be favored. However, for the single-product indirect liquefaction processes, advanced high-temperature gasifiers, rather than the commercially proven Lurgi gasifier assumed for these estimates, may be used. This adds some additional uncertainty to product costs.

Despite the inability to make reliable absolute cost estimates, some comparisons based on technical arguments are possible. First, oil shale probably will be one of the lower cost synfuels because of the relative technical simplicity of the process: one simply heats the shale to produce a liquid syncrude which is then hydrogenated to produce a high-quality substitute for natural crude oil. However, handling the large volumes of shale may be more difficult than anticipated; and, since the high-quality shale resources are located in a single region and there is only a limited ability to disperse plants as an environmental measure, large production volumes could necessitate particularly stringent and therefore expensive pollution control equipment or increase waste disposal costs.

Second, regarding the indirect transportation liquids from coal, the relative consumer cost (cost per miles driven) of methanol v. synthetic gasoline will depend critically on automotive technology. Although methanol plants are somewhat less complex than coal-to-gasoline plants, the cost difference is overcome by the higher cost of terminalling and transporting methanol to a service station, due to the latter's lower energy content per gallon. With specially designed engines, however, the methanol could be used with about 10 to 20 percent higher efficiency than gasoline. This would reduce the apparent cost of methanol, making it slightly less expensive (cost per mile) than synthetic gasoline.* Successful development of direct injected stratified-charge engines would eliminate this advantage, while successful development of advanced techniques for using methanol as an engine fuel could increase methanol's advantage.**

This analysis shows that there is much uncertainty in these types of cost estimates, and they should be treated with due skepticism. The estimates are useful as a general indication of the likely cost of synfuels, but these and any other cost estimates available at this time are inadequate to serve as a principal basis for policy decisions that require accurate cost predictions with consequences 10 to 20 years in the future.

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[24] Process Gas Consumer Group, *Process Gas Consumers Report*, Washington, D.C., June 1981.

[25] J. F. Bookout, Chairman, Committee on Unconventional Gas Sources, "Unconventional Gas Sources," National Petroleum Council, December 1980.

*If gasoline has a $0.10/gge advantage in delivered fuel price for synfuels costing $1.50/gge, methanol would have an overall $0.20/gge advantage when used with a specially designed engine. This could pay for the added cost of a methanol engine in 2 to 4 years (assuming 250/gge consumed per year).

**For example, engine waste heat can be used to decompose the methanol into carbon monoxide and hydrogen before the fuel is burned. The carbon monoxide/hydrogen mixture contains 20 percent more energy than the methanol from which it came, with the energy difference coming from what would otherwise be waste heat.

DEVELOPING A SYNFUELS INDUSTRY

Development of a U.S. synfuels industry can be roughly divided into three general stages. During the first phase, processes will be developed and proven and commercial-scale operation established. The second phase consists of expanding the industrial capability to build synfuels plants. In the third stage, synfuels production is brought to a level sufficient for domestic needs and possibly export. Current indications are that the first two stages could take 7 to 10 years each. Some of the constraints on this development are considered next, followed by a description of two synfuels development scenarios.

Constraints

A number of factors could constrain the rate at which a synfuels industry develops. Those mentioned most often include:

- *Other Construction Projects.*—Construction of, for example, a $20 billion to $25 billion Alaskan natural gas pipeline or a $335 billion Saudi Arabian refinery and petrochemical industry, if carried out, would use the same international construction companies, technically skilled labor, and internationally marketed equipment as will be required for U.S. synfuel plant construction.[26]
- *Equipment.*—Building enough plants to produce 3 million barrels per day (MMB/D) of fossil synfuels by 2000 will require significant fractions of the current U.S. capacity for producing pumps, heat exchangers, compressors and turbines, pressure vessels and reactors, alloy and stainless steel valves, draglines, air separation (oxygen) equipment, and distillation towers.[27] [28] [29] [30]
- *Critical Materials.*—Materials critical to the synfuels program include cobalt, nickel, molybdenum, and chromium. Two independent analyses concluded that only chromium is a potential constraint.[31] [32] (Currently, 90 percent of the chromium used in the United States is imported.) However, development of 3 MMB/D of fossil synfuels production capacity by 2000 would require only 7 percent of current U.S. chromium consumption.[33]
- *Technological Uncertainties.*—The proposed synfuels processes must be demonstrated and shown to be economic on a commercial scale before large numbers of plants can be built.
- *Transportation.*—If large quantities of coal are to be transported, rail lines, docks, and other facilities will have to be upgraded.[34] New pipelines for syncrudes and products will have to be built.
- *Manpower.*—A significant increase in the number of chemical engineers and project managers will be needed. For example, achieving 3 MMB/D of fossil synfuels capacity by 2000 will require 1,300 new chemical engineers by 1986, representing a 35-percent increase in the process engineering work force in the United States.[35] More of other types of engineers, pipefitters, welders, electricians, carpenters, ironworkers, and others will also be needed.
- *Environment, Health, and Safety.*—Delays in issuing permits; uncertainty about standards, needed controls, and equipment performance; and court challenges can cause delays during planning and construction (see ch. 10). Conflicts over water availability could further delay projects, particularly in the West (see ch. 11).
- *Siting.*—Some synfuels plants will be built in remote areas that lack the needed technical and social infrastructure for plant construction. Such siting factors could, for example, increase construction time and cost.
- *Financial Concerns.*—Most large synfuels projects require capital investments that are large relative to the total capital stock of the company developing the project. Consequently, most investors will be extremely cautious with these large investments and banks may be reluctant to loan the capital without extensive guarantees.

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[26] *Business Week*, Sept. 29, 1980, p. 83.

[27] Ibid.

[28] Bechtel International, Inc., "Production of Synthetic Liquids From Coal: 1980-2000, A Preliminary Study of Potential Impediments," final report, December 1979.

[29] TRW, op. cit.

[30] Mechanical Technology, Inc., "An Assessment of Commercial Coal Liquefaction Processes Equipment Performance and Supply," January 1980.

[31] Ibid.

[32] Bechtel International, Inc., op. cit.

[33] Ibid.

[34] *The Direct Use of Coal: Prospects and Problems of Production and Combustion*, OTA-E-86 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

[35] Bechtel International, Inc., op. cit.

None of these factors can be identified as an overriding constraint for coal-derived synfuels, although the need for commercial demonstration and the availability of experienced engineers and project managers appear to be the most important. There is still disagreement about how important individual factors like equipment availability actually will be in practice. However, the more rapidly a synfuels industry develops, the more likely development will cause significant inflation in secondary sectors, supply disruptions, and other externalities and controversies. But the exact response of each of the factors in synfuels development is not known. For oil shale, on the other hand, the factor (other than commercial demonstration) that is most likely to limit the rate of growth is the rate at which communities in the oil shale regions can develop the social infrastructure needed to accommodate the large influx of people to the region.[36]

The major impacts of developing a large synfuels industry are discussed in chapters 8 through 10, while two plausible synfuels development scenarios are described below.

Development Scenarios

Based on previous OTA reports[37] [38] estimates of the importance of the various constraints discussed above, and interviews with Government and industry officials, two development scenarios were constructed for synthetic fuels production. It should be emphasized that these are not projections, but rather plausible development scenarios under different sets of conditions. Fossil synthetics are considered first, followed by biomass synfuels; and the two are combined in the final section.

Fossil Synfuels

The two scenarios for fossil synthetics are shown in table 49 and compared with other estimates in figure 16. It can be seen that OTA scenarios are reasonably consistent with the other projections, given the rather speculative nature of this type of estimate.

Table 49.—Fossil Synthetic Fuels Development Scenarios (MMB/DOE)

Fuel	Year 1980	1985	1990	1995	2000
Low estimate					
Shale oil	—	0	0.2	0.4	0.5
Coal liquids	—	—	0.1	0.3	0.8
Coal gases	—	0.09	0.1	0.3	0.8
Total	—	0.1	0.4	1.0	2.1
High estimate					
Shale oil	—	0	0.4	0.9	0.9
Coal liquids	—	—	0.2	0.7	2.4
Coal gases	—	0.09	0.2	0.7	2.4
Total	—	0.1	0.8	2.3	5.7

SOURCE: Office of Technology Assessment.

In both scenarios, the 1985 production of fossil synthetic fuels consists solely of coal gasification plants, the only fossil synfuels projects that are sufficiently advanced to be producing by that date. For the high estimate it is assumed that eight oil shale, four coal indirect liquefaction, and three additional coal gasification plants have been built and are operating by 1988-90. If no major technical problems have been uncovered, a second round of construction could proceed at this time.

Assuming that eight additional 50,000-bbl/d plants are under construction by 1988 and that construction starts on eight more plants in 1988 and the number of starts increases by 10 percent per year thereafter, one would obtain the quantities of synfuels shown for the high estimate. Ten-percent annual growth in construction starts was chosen as a high but probably manageable rate of increase once the processes are proven.

Oil shale is assumed to be limited to 0.9 MMB/D because of environmental constraints and, possibly, political decisions related to water availability. Some industry experts believe that neither of these constraints would materialize because, at this level of production, it would be feasible to build aqueducts to transport water to the region, and additional control technology could limit

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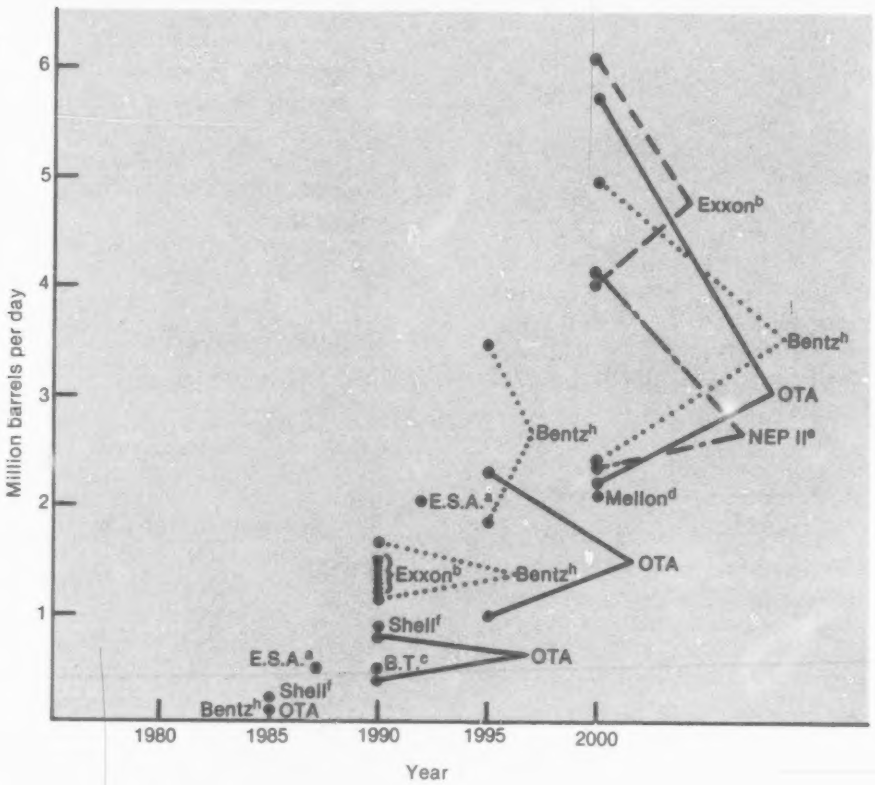
[36] *An Assessment of Oil Shale Technologies*, op. cit.

[37] Ibid.

[38] *Energy From Biological Processes*, op. cit.

Figure 16.—Comparison of Fossil Synthetic Fuel Production Estimates



[a] Energy Security Act, Public Law 96-294 6/30/80, sec. 100 (a) (2).
[b] Exxon Energy Outlook, December 1979. These data are consistent with those in Exxon Energy Outlook, December 1980.
[c] Bankers Trust Forecast—as reported in *Synfuels*, Aug. 15, 1980.
[d] Mellon Institute Forecast—as reported in *Synfuels*, Aug. 22, 1980.
[e] National Energy Plan II, May 1979.
[f] National Transportation Policy Study Commission Report, July 1979.
[g] Shell National Energy Outlook, preliminary version, Feb. 19, 1980.
[h] E. J. Bentz and Associates, "Selected Technical and Economic Comparisons of Synfuel Options," contractor report to OTA, April 1981.

SOURCE: E. J. Bentz and Associates, "Selected Technical and Economic Comparisons of Synfuel Options," contractor report to OTA, 1981; modified by OTA.

plant emissions to an acceptable level. If this is done and salt leaching into the Colorado River does not materialize as a constraint, perhaps more of the available capital, equipment, and labor would go to oil shale and less to the alternatives.

The low estimate was derived by assuming that project delays and poor performance of the first round of plants limit the output by 1990 to about 0.4 MMB/D. These initial problems limit investment in new plants between 1988-95 to about the level assumed during the 1981-88 period, but the second round of plants performs satisfactorily. This would add 0.6 MMB/D, assuming that the first round operated at 60 percent of capacity, on the average, while the second round operated at 90 percent of capacity (i.e., at full capacity 90 percent of the time). Following the second round, new construction starts increase as in the high estimate.

In both estimates, it is assumed that about half of the coal synfuels are gases and half are liquids.

This could occur through a combination of plants that produce only liquids, only gases, or liquid/gas coproducts. Depending on markets for the fuels, the available resources (capital, engineering firms, equipment, etc.) could be used to construct facilities for producing more synthetic liquids and less synthetic gas without affecting the synfuels total significantly.

When interpreting the development scenarios, however, it should be emphasized that there is no guarantee that even the low estimate will be achieved. Actual development will depend critically on decisions made by potential investors within the next 2 years. In addition to businesses' estimates of future oil prices, these decisions are likely to be strongly influenced by availability of Federal support for commercialization, in which commercial-scale process units are tested and proven. Unless several more commercial projects than industry has currently announced are initiated in the next year or two, it is unlikely that even the low estimate for 1990 can be achieved.

Biomass Synfuels

Estimating the quantities of synfuels from biomass is difficult because of the lack of data on the number of potential users, technical uncertainties, and uncertainties about future cropland needs for food production and the extent to which good forest management will actually be practiced. OTA has estimated that from 6 to 17 quadrillion Btu per year (Quads/yr) of biomass could be available to be used for energy by 2000, depending on these and other factors.[39] At the lower limit, most of the biomass would be used for direct combustion applications, but there would be small amounts of methanol, biogas, ethanol from grain, and gasification as well.

Assuming that 5 Quads/yr of wood and plant herbage, over and above the lower figure for bioenergy, is used for energy by 2000 and that 1 Quad/yr of this is used for direct combustion, then about 4 Quads/yr would be converted to synfuels. If half of this biomass is used in airblown gasifiers for a low-Btu gas and half for methanol synthesis (60 percent efficiency), this would result in 0.9 million barrels per day oil equivalent (MMB/DOE) of low-Btu gas and 0.6 MMB/DOE of methanol (19 billion gal/yr).*

The 0.9 MMB/DOE of synthetic gas is about 5 percent of the energy consumption in the residential/commercial and industrial sectors, or 9 percent of total industrial energy consumption. Depending on the actual number of small energy users located near biomass supplies, this figure may be conservative for the market penetration of airblown gasifiers. Furthermore, the estimated quantity of methanol is contingent on: 1) development of advanced gasifiers and, possibly, prefabricated methanol plants that reduce costs to the point of being competitive with coal-derived methanol and 2) market penetration of coal-derived methanol so that the supply infrastructure and end-use markets for methanol are readily available. OTA's analysis indicates that both assumptions are plausible.

In addition to these synfuels, about 0.08 to 0.16 MMB/DOE (2 billion to 4 billion gal/yr) of ethanol** could be produced from grain and sugar

Box D.—Definitions of Demonstration and Commercial-Scale Plants

After laboratory experiments and bench-scale testing show a process to be promising, a demonstration plant may be built to futher test and "demonstrate" the process. This plant is not intended to be a moneymaker and generally has a capacity of several hundred to a few thousand barrels per day. The next step may be various stages of scale up to commercial scale, in which commercial-scale process units are used and proven, although the plant output is less than would be the case for a commercial operation. For synfuels, the typical output of a commercial unit may be about 10,000 bbl/d. A commercial plant would then consist of several units operating in parallel with common coal or shale handling and product storage and terminal facilities.

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[39] Ibid.

*If advanced biomass gasifiers methanol can be produced with an overall efficiency of 70 percent for converting biomass to methanol, this figure will be raised to 0.7 MMB/DOE or 22 billion gal/yr.

**Caution should be exercised when interpreting the ethanol levels, however, since achieving this level will depend on a complex balance of various forces, including Government subsidies, market demand for gasohol, and gasohol's inflationary impact on food prices.

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crops, and perhaps 0.1 MMB/DOE of biogas and SNG from anaerobic digestion.* Taking these contributions together with the other contributions from biomass synfuels results in the high and low estimates given in table 50.

Summary

Combining the contributions from fossil and biomass synfuels results in the two development scenarios shown in figure 17. Coal-derived synfuels provide the largest potential. Ultimately, production of fossil synfuels is likely to be limited by the demand for the various synfuel products, the emissions from synfuels plants, and the cost of reducing these emissions to levels required by law. Beyond 2000, on the other hand, synfuels from biomass may be limited by the resource availability; however, development of energy crops capable of being grown on land unsuitable for food crops, ocean kelp farms, and other speculative sources of biomass could expand the resource base somewhat.

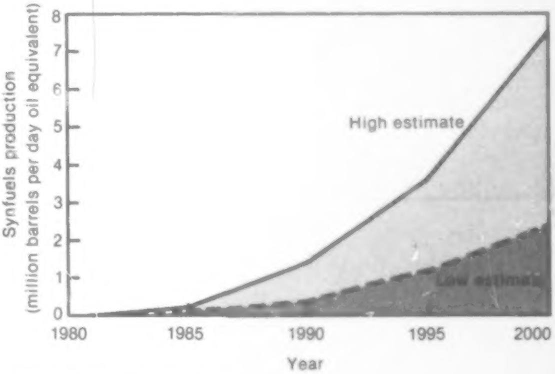
Table 50.—Biomass Synthetic Fuels Development Scenarios (MMB/DOE)

Fuel	Year 1980	1985	1990	1995	2000
Low estimate					
Methanol[a b]	—	(e)	(e)	(e)	0.1
Ethanol[c]	(e)	(e)	(e)	(e)	(e)
Low- and medium-energy fuel gas[a]	(e)	(e)	(e)	0.1	0.1
Biogas and methane[d]	(e)	(e)	(e)	(e)	(e)
Total	(e)	(e)	(e)	0.2	0.3
High estimate					
Methanol[a b]	—	(e)	0.1	0.3	0.6
Ethanol[c]	(e)	(e)	0.1	0.1	0.1
Low- and medium-energy fuel gas	(e)	0.1	0.3	0.7	0.9
Biogas and methane[d]	(e)	(e)	0.1	0.2	0.2
Total	(e)	0.1	0.6	1.3	1.8

[a] From wood and plant herbage and possibly municipal solid waste.
[b] Ethanol could also be produced from wood and plant herbage, but methanol is likely to be a less expensive liquid fuel from these sources.
[c] From grains and sugar crops.
[d] From animal manure, municipal solid waste, and, possibly, kelp.
[e] Less than 0.1 MMB/DOE.

SOURCE: Office of Technology Assessment.

Figure 17.—Synthetic Fuel Development Scenarios



SOURCE: Office of Technology Assessment.

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*The total potential from manure is about 0.14 MMB/DOE, but the net quantitity that may be used to replace oil and natural gas is probably no more than 50 percent of this amount. In addition, there may be small contributions from municipal solid waste and, possibly, kelp.

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Stationary Uses of Petroleum

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Chapter 7

Stationary Uses of Petroleum

INTRODUCTION

Stationary users—buildings, industry, and electric utilities—consumed about 8.1 million barrels per day (MMB/D) of petroleum products in 1980. While the potential for reducing oil use by these sectors is well recognized, it has not received as much attention as oil reduction opportunities in transportation. Indeed, U.S. energy policies in the 1970's implicitly encouraged increased oil use for stationary purposes. Lately, however, policy objectives have been set to encourage reduction in oil use by fuel switching and conservation. These objectives include conservation goals and incentives to increase energy use efficiency by buildings and industry, and fuel-switching goals to convert utility and large industrial boilers from oil and natural gas to coal.

Photo credit: Department of Energy

Cracks and very narrow spaces, such as those around window framing are insulated to increase energy use efficiency

This section examines the current mix of petroleum products used in the stationary sector and recent trends. A Department of Energy forecast of stationary demand on petroleum products was selected to serve as a baseline. This will be used to provide estimates of the volume of fuel oil that can be saved by either conservation or conversion to new natural gas and electricity. Readers should note that these estimates only describe reductions in oil use that are technically and economically plausible. Whether the estimated reductions are actually realized depends on how numerous energy users and producers react to economic incentives and other factors affecting their choices. Some of these factors are discussed at the end of this section.

CURRENT SITUATION

Table 51 shows petroleum use by the stationary and transportation sectors since 1965.

Stationary sectors have accounted for 45 to 48 percent of total petroleum demand over this period. Demand growth has occurred in industry and electric utilities as a result of natural-gas curtailments during the 1970's, environmental restrictions on coal, and the rapid increase in electricity demand since about 1973. The type of petroleum product used is also important, since we are primarily concerned with products most readily converted to transportation fuels. Table 52 shows the distribution of major petroleum products for 1980 among the stationary and transportation sectors.

As fuel, the stationary sectors consume principally middle distillates and residual oil. The major components of the other category includes petrochemical feedstocks, asphalt, petroleum coke, and refinery still gas. These are unlikely

Table 51.—U.S. Petroleum Demand (MMB/D)

	Stationary				Transportation
Year	Industry	Buildings	Utilities	Total	Total
1965	2.2	3.0	0.3	5.5	6.0
1970	2.5	3.5	0.9	6.9	7.8
1975	2.8	3.2	1.4	7.4	8.9
1980	3.6	2.9	1.6	8.1	8.7

SOURCE: Department of Energy, Energy Information Administration, *1980 Annual Report to Congress*, vol. II.

candidates for conversion to transportation fuels because modifications to refineries would be required far beyond those needed to convert residual fuel oil.[1] Further, some of these products, such as the petrochemical feedstocks and asphalt, could only be replaced by synthetic liquids. The liquefied petroleum gases (LPGs) can be used directly as a transportation fuel, as is the case with cars and trucks that have been modified to run on propane. Widespread adoption will depend principally on the relative cost of propane compared with gasoline, diesel fuel, and methanol when the cost of motor vehicle conversion is included.

Since the current price of natural gas liquids—the major source of propane—is and is likely to remain as high as the price of domestic crude oil, a significant shift to propane-powered vehicles is not likely. Therefore, LPG was not considered in this analysis of stationary fuel use. The major target of fuel switching and conservation, then, is the 4.4 MMB/D of distillate and residual fuel oil in current use. They can be used as a transportation fuel, although it will be necessary to upgrade residual fuel to gasoline and middle distillates by modifying the refinery process. Such modification is under way but will require considerable time and investment.[2]

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[1] *Refining Flexibility* (Washington, D.C.: National Petroleum Council, 1980).

[2] *Oil and Gas Journal*, Jan. 5, 1981, p. 43.

Table 52.—1980 Petroleum Demand (MMBD)[a]

	Stationary				Transportation
Product	Buildings	Industry	Electricity	Total	Total
Gasoline	0	0	0	0	6.3
Distillate	1.0	0.7	0.2	1.9	0.95
Residual	0.5	0.65	1.3	2.45	0.4
Jet	0	0	0	0	1.1
LPG	0.3	0.7	0	1.0	0
Other	0.7	2.0	0	2.7	0.2

[a] Given in terms of product equivalent—5.5 million Btu per Barrel.

SOURCE: Department of Energy, Energy Information Administration, *1980 Annual Report to Congress*, vol. II.

FUTURE DEMAND

Over the next decade some of this 4.4 MMB/D will be eliminated by fuel switching and conservation as the price of oil rises. Indeed, a decline of 1.1 MMB/D took place between 1979 and 1980.[3] How much more is possible by 1990 depends on future oil prices, the costs of alternatives, the ability to finance these alternatives, and environmental and regulatory factors. The 1980 Energy Information Administration (EIA) estimate of 1990 demand is shown in table 53. This fore-

Table 53.—1990 EIA Petroleum[a] Demand Forecast for Stationary Fuel Uses (MMB/D)[b]

Product	Buildings	Industry	Electricity	Total
Distillate	0.9	0.1	0.15	1.4
Residual	0.3	0.2	0.9	1.15
Total	1.2	0.3	1.05	2.55

[a] The "other" and LPG category of stationary petroleum demand is forecast to remain at its 1980 level of 3.8 MMB/D. This category, however, would then increase from 46 percent of all stationary uses in 1980 to 60 percent in 1990. It has proven to be much less elastic to fuel price increases since 1973 than the distillate—residual fuel category.

[b] Barrel of product—5.5 MMBtu per barrel.

SOURCE: Department of Energy, Energy Information Administration, *Annual Report to Congress*, vol. III.

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[3] *1980 Annual Report to Congress, Vol. 2*, DOE/EIA-0173(80)/2 (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, 1980).

cast is based on a 1990 oil price of $45 per barrel (bbl) (in 1980 dollars).

The forecast reduction of 1.8 MMB/D over the next 10 years (from 4.4 MMB/D in 1980 to 2.6 MMB/D in 1990) would be accomplished by more efficient use, and by conversion to coal, electricity, and natural gas. Beyond 1990, continued reduction can be expected, particularly in the electric utility sector, if the economic advantages of alternate fuels and conservation continue.

For the purpose of this study, OTA determined the technology (alternate fuels, conservation) and investment necessary to eliminate this 2.6-MMB/D usage during the 1990's. This is about the same level of reduction that can be achieved by going from a new-car fleet average of 30 miles per gallon (mpg) in 1985 to an average of 65 mpg in 1995,* and is close to the target synthetic fuels production level by 1992 set forth in the Energy Security Act.[4] Therefore, it provides a good comparison for the remainder of the study. The rest of this chapter describes how this elimination might be achieved and what it might cost.

First, fuel switching alone is considered, and second, conservation. OTA did not attempt to estimate a timetable other than to assume that the reductions take place throughout the 1990's. This is consistent with the time needed to introduce similar savings from increased auto efficiency or from synthetic fuels production.* Where possible, serious time constraints that may appear are mentioned. The focus, however, is on investment costs and resource requirements. It is important to emphasize that because OTA's calculations were based on the EIA 1990 forecast, costs of fuel switching and conservation necessary to go from the 1980 to 1990 levels of fuel oil consumption were not counted. This somewhat arbitrary decision will bias against conservation and fuel switching, since the least costly steps are expected to be taken first, during the 1980's.

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*See ch. 5, p. 127.

[4] 42 USC 8701, Energy Security Act, June 30, 1980.

*See ch. 5, p. 127; ch. 6, p. 177.

FUEL SWITCHING

The prime candidates for eliminating this 2.6 MMB/D of fuel oil by fuel switching are natural gas, coal, and electricity from coal and natural gas. Indeed, a considerable amount of the oil now used by industry (about 20 percent) is a result of converting from natural gas to oil during the mid-1970's.[5] This was partially a result of the Federal curtailment policy for natural gas that gave low priority in many industrial applications (primarily boilers). Further, the uncertainty of supply that existed during that same period caused industry to switch other applications from natural gas to oil as well. In the buildings sector, "scarcity" of natural gas during the 1970's, combined with the rapid rise in its price, caused a temporary halt in the growth rate of natural gas use. There was no corresponding growth in petroleum use, however, unlike the case with industry, since electricity was the primary replacement energy.

Complete replacement of fuel oil in buildings by natural gas alone would require about 2.4 trillion cubic feet per year (TCF/yr), assuming current end-use efficiency. If only electricity were used, 425 billion kWh/yr of delivered electric energy would be needed assuming an end-use efficiency increase of 67 percent.* By 1990, most of the industrial processes that can use coal (primarily large boilers) will have been converted because of the large difference in coal and oil prices that currently exists.[6] If all the remaining fuel oil used by industry were displaced by natural gas alone, 0.6 TCF/yr would be required, assuming no change in end-use efficiency. If electricity alone were used, about 120 billion kWh/yr of delivered electric energy would be needed, assuming a 50-percent increase in end-use efficiency.*

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[5] *1980 Annual Report to Congress, Vol. 2,* op. cit., pp. 65 and 107. This claim is inferred from these two tables which show a drop in natural gas consumption by industry between 1974 to 1979 of over 20 percent and a corresponding increase in industrial oil consumption.

*Assuming heat pumps (water and space) with a seasonal performance factor of 1.25 compared to oil furnaces with a seasonal performance factor of 0.75.

[6] *Cost and Quality of Fuels for Electric Utility Plants, February 1981,* DOE/EIA-0075(81/02) (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, 1981), p. 3.

For electric utilities, residual fuel oil is primarily used in baseload steam plants, while distillate oil is used for peaking turbines. To replace the former by coal would require 135 million tons, and to replace the latter by natural gas would require 0.3 TCF/yr.** Table 54 summarizes the amount of energy needed to replace oil in each sector, assuming that each substitute energy source is used *exclusively*.

The first question to ask is whether these substitute resources will be available. Forecasts for domestic natural gas production during the 1990's by Exxon and EIA are about 14 to 16 TCF/yr.[7] Of this, about 70 percent will come from existing reserves, while the remaining will come from new reserves including so-called unconventional gas; i.e., gas from tight sands, geopressured brine, coal seams, and Devonian shale. These latter resources are of particular interest since they are the likely source of any domestic natural gas, above that now forecast, that would be needed to replace stationary fuel oil during the 1990's.

EIA currently forecasts unconventional gas production increasing from 1.3 TCF in 1990 to 4.4 TCF in 2000 at a production cost of about $5.50 to $6.50/MCF (in 1980 dollars).[8] EIA predicts, however, that additional volumes of unconventional gas will become available in the 1990's if natural gas reaches what would then be the world price of oil (about $56/bbl in 1980 dollars). The National Petroleum Council recently made a similar claim, predicting as much as an additional 10 TCF/yr becoming available by 2000.[9] Therefore, it appears that production of an additional 3.3 TCF/yr (relative to that now forecast by EIA and Exxon) could be possible by the mid-1990's at gas production prices equivalent to about $56/bbl of oil (1980 dollars).

These cost estimates are subject to a great deal of uncertainty, however, and the actual cost of this unconventional gas could be considerably higher. There is less uncertainty about the ability to produce this gas increment from unconventional sources—particularly tight sands—but other alternatives, including synthetic natural gas from coal, may be cheaper.

Next, consider electricity. Current generation capacity in the United States is 600,000 MW (including 100,000 MW using oil) operating at an overall capacity factor of 45 percent.[10] Although increasing the capacity factor to 65 percent while concurrently converting all oil units to coal would provide the quantity of electricity needed (see table 54), that path may not be practical. The pro-

Table 54.—Summary of Energy Requirements for Displacing 1990 Fuel Oil

	1990 petroleum forecast (EIA) (MMB/D)	Replacement energy sources: Natural gas (TCF)	Electricity (billion kWh)	Coal (million tons)
Buildings	1.2	2.4	425	—
Industry	0.3	0.6	120	—
Utilities	0.9 (residual)	—	—	135
	0.15 (distillate)	0.3	—	—
Total	2.55	3.3	545	135

SOURCE: Office of Technology Assessment.

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*Assuming an end-use efficiency of 100 percent for electric heat, compared with 67 percent for oil-fired units. If combustion turbines are replaced by electric motors for mechanical drive a similar increase will occur.

**It was assumed that there would be no change in conversion efficiency upon replacing the residual and distillate oil generation by coal and natural gas generation.

[7] *Energy Outlook 1980-2000* (Houston, Tex.: Exxon Co., U.S.A., December 1980), p. 10; *1980 Annual Report to Congress, Vol. 3*, DOE/EIA 0173(80)/3 (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, 1980), p. 87.

[8] Ibid., p. 88.

[9] *Unconventional Gas Sources, Executive Summary*, (Washington, D.C.: National Petroleum Council, December 1980), p. 5.

[10] *Electric Power Supply and Demand, 1981-1990* (Princeton, N.J.: National Electric Reliability Council, July 1981).

file describing the fuel oil load of buildings for heating peaks rather sharply during the winter, and nearly all of the electric energy required to replace fuel oil would need to be generated during the 5 months of the heating season. Since the load profile is the primary determinant of the capacity factor, conversion to electric space and water heating will likely do little to increase the overall capacity factor. Therefore, as much as 120,000 MW of new capacity may be needed.*

The ease with which this much capacity could be added depends on the growth rate for electricity for the remainder of the century in the absence of this oil-to-electricity conversion (underlying rate), and the financial health of the electric utility industry. These two points are obviously related because an industry which has difficulty raising capital, as is now the case,[11] will have difficulty meeting new generation requirements of any kind. Currently forecasts of the electric demand growth rate range from near zero (by the Solar Energy Research Institute (SERI))[12] to about 3.8 percent per year (by the National Electric Reliability Council).[13]

In the latter case, capacity additions become so great during the 1990's that the full increment of capacity needed for fuel oil replacement (120,000 MW) could be met if the underlying rate dropped to 3.2 percent per year but the utilities continued building at 3.8 percent per year. If growth of electricity demand in the absence of our hypothetical fuel switching dropped to 2 percent per year, a capacity addition rate of 3 percent per year would meet both underlying demand and the fuel-switching demand. Under these conditions, annual capital requirements would be approximately $25 billion to $35 billion (1980 dollars) and annual capacity addition would average about 27,000 MW. These are values below those attained by the utility industry during the early 1970's.[14] This is manageable provided the current financial problems are solved. If not, providing the replacement electricity from new capacity is unlikely.

Finally, there is the question of conversion of the electric powerplants that will still be burning oil in 1990 to other fuels (primarily coal). There should be little difficulty producing the extra coal for conversion of the plants burning residual fuel oil.[15] Further, as seen above, the natural gas could be available as a fuel in those plants burning distillate. There are barriers to converting existing plants including environmental problems of coal, the technical problems in actually converting many of these powerplants, and difficulties in financing the conversion projects. In many cases it may be less costly to build a new powerplant at a different site and retire the existing oil-fired plant.

Considering the physical requirements alone, however, there could be adequate supplies, during the 1990's, to replace 2.6 MMB/D of distillate and residual fuel oil by some combination of natural gas and electricity along with coal (or possibly nuclear) to replace the oil-fired electric utility boilers.

Although the cost of this process is difficult to calculate, it is possible to make an estimate by making several arbitrary, but plausible assumptions based on the above analysis and current operating conditions. First, it is assumed that natural gas replaces all of the fuel oil used by industry and utility combustion turbines, and half the heating oil used by buildings. Second, it is assumed that electricity is used to replace the other half of the heating oil used by buildings. Finally, all electric powerplants using residual fuel oil are replaced by coal conversions or new coal-fired powerplants. Table 55 summarizes the replacement energy requirements for this scenario.

To estimate the costs of eliminating this 2.6 MMB/D of fuel oil by fuel switching, the following costs (in 1980 dollars) for the replacement energy were used:

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*This is the capacity required to produce 545 billion kWh operating at the current coal-fired average capacity factor of 52 percent.

[11] "The Current Financial Condition of the Investor-Owned Electric Utility Industry and Possible Federal Actions to Improve It," Edison Electric Institute before the Federal Energy Regulatory Commission, Mar. 6, 1981.

[12] *Building a Sustainable Future, Vol. 2,* prepared by the Solar Energy Research Institute, Committee on Energy and Commerce, U.S. House of Representatives, Washington, D.C., April 1981, p. 837.

[13] *Electric Power Supply and Demand, 1981-1990,* op. cit.

[14] *Electrical World,* Sept. 15, 1980, p. 69.

[15] *The Direct Use of Coal,* OTA-E-86 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

Table 55.—Annual Replacement Energy Requirements[a]

	Buildings	Industry	Electric utilities	Total
Natural gas (TCF) . . .	1.2	0.6	0.3	2.1
Electricity (billion kWh)	225[b]	—	—	225
Coal (million tons) . .	—	—	135[c]	135

[a] Assumes an increase in end-use efficiency of 67 percent when switching from fuel oil to electricity for space or water heating and no change when switching from fuel oil to natural gas in any of the three sectors.

[b] Requires 50,000 MW operating at a 50 percent capacity factor.

[c] Assumes the 1990 oil-fired capacity, which is now forecast to operate at a 35 percent capacity factor (NERC), can be replaced by 55,000 MW of coal-fired capacity operating at 57.5 percent capacity factor.

SOURCE: Office of Technology Assessment.

1. New coal-fired electric powerplants cost $900/kW, including all necessary environmental controls.[16]
2. Investment costs for natural gas from unconventional sources (tight sands) are approximately $16,500/MCF per day.[17] Operating costs, including transmission and distribution, are about $1.30/MCF.[18]
3. The investment cost for new coal surface mines is approximately $9,000/ton of coal per day. Operating costs are about $6.50/ton.[19]
4. The cost to convert oil fired capacity to coal is estimated at $600/kW.[20]

All of these costs are in 1980 dollars. Therefore, they will underestimate the actual costs of conversion in the 1990's to the extent there are real increases in these costs between new and the mid-1990's. Cost estimates are also needed for the end-use equipment. This was simplified by assuming no change is needed for industry and combustion turbines in converting from distillate to natural gas. For buildings, heat pumps are used when electricity is the new energy source, and new gas furnaces are used for natural gas. Based on current retail estimates these costs are $2,000 and $1,200, respectively (1980 dollars), for units capable of delivering 100 million Btu of heat per heating season, and having the capacity to meet the peak-hour heating load.[21] Table 56 summarizes the investment costs per barrel per day replaced for each sector.

The total investment, obtained by multiplying the per unit investment (table 56) by the amount of oil replaced (table 55), is about $230 billion (1980 dollars). These estimates include production of the energy resource (electric generating plants, natural gas, and coal mines) and end-use equipment when needed. They do not include costs to construct new transmission and distribution facilities that might be needed. This omission will be discussed below.

Table 56.—Investment Costs For Fuel Oil Replacement Energy[a b]

	Buildings	Industry	Utilities
Natural gas	121,000	100,000	90,000
Electricity	110,000	—	—
Coal	—	—	54,000

[a] Dollars per barrel of oil replaced per day.

[b] Includes investment cost necessary to upgrade the replaced residual fuel oil to gasoline and diesel where applicable. Cost is $14,000/bbl of residual per day on the average. Purvin and Gertz, Inc., *An Analysis of Potential for Upgrading Domestic Refining Capacity*, prepared for the American Gas Association, Arlington, Va., March 1980.

SOURCE: Office of Technology Assessment.

CONSERVATION

The other major alternative for reducing oil use in the stationary sectors is conservation. Conservation cannot completely eliminate fuel oil use by itself—but it can reduce it, and possibly free enough natural gas and electricity to substitute for the remaining fuel oil. There have been numerous estimates of conservation potential for buildings and industry in the past several years.

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[16] *Technical Assessment Guide*, EPRI PS-1201-SR (Palo Alto, Calif.: Electric Power Research Institute, July 1979), pp. 8-11.

[17] *Unconventional Gas Sources, Tight Gas Reservoirs, Part 1*, op. cit., pp. E-115.

[18] "Natural Gas Issues" (Arlington, Va.: American Gas Association, May 1981), p. 8.

[19] "Comparative Analysis of Mining Synfuels" (Los Angeles, Calif.: Fluor Corp., 1981).

[20] "The Regional Economic Impacts on Electricity Supply of the Powerplant and Industrial Fuel Use Act and Proposed Amendments" (Washington, D.C.: Edison Electric Institute, April 1980), p. 37.

[21] Academy Airconditioning Co., Rockville, Md., private communication.

The most detailed analysis is that recently completed by SERI.[22]

The SERI estimates are used to examine the possibility of and potential costs for eliminating stationary uses of fuel oil over the period 1990-2000. OTA has used the SERI analysis of conservation measures in the buildings sector to obtain an approximation of the costs of eliminating the remaining stationary uses of fuel oil in all sectors in the 1990-2000 period. These conservation measures reduce the use of fuel oil, electricity, and natural gas. The electricity and natural gas saved is used to replace the fuel oil remaining after the conservation. In table 57, the SERI projection for 2000 is given, by fuel, along with the savings obtained relative to the 1990 baseline demand (EIA forecast). The savings are the difference between the SERI 2000 projection and the EIA 1990 forecast.* As shown in table 57, conservation could eliminate 67 percent of the fuel oil used by buildings and provide more than enough natural gas to eliminate the remaining fuel oil used in both buildings and industry, as well as distillate used by electric utilities. Finally, enough electricity would be saved to replace the electricity produced by oil-fired generation (see table 54). The amount of natural gas and electricity needed to do this are given in the last column of table 57. About 65 percent of the SERI estimated savings for the buildings sector alone will achieve the goal.

The SERI study estimated an investment cost of $335 billion (in 1980 dollars) to achieve their savings goals for 2000.* [23] If we arbitrarily allocate these costs to the portion of the savings needed solely for fuel oil elimination, the cost investment for the scenario is about $215 billion (65 percent of total). In addition, investment is needed in converting end-use equipment from fuel oil to natural gas in buildings for oil not eliminated by conservation. Using the procedure described in the previous section, this amounts to about $10 billion. The total investment for these measures is $225 billion—equivalent to $88,000/bbl of oil replaced per day.

Table 57.—Energy Made Available by Conservation

Energy source	SERI demand estimate (2000)	EIA demand estimate (1990)	Savings by 2000	Savings used for oil substitution
Fuel oil (MMB/D)	0.4	1.2	0.8	—
Natural gas (TCF/yr).......	4.5	7.8	3.3	1.7
Electricity (billion kWh/yr)..	1140	1580	440	250

SOURCE: Office of Technology Assessment.

DISCUSSION

The analysis described gives a plausible estimate of the technical and investment requirements of eliminating stationary uses of oil between 1990 and 2000. These requirements are not forecasts, as mentioned above, but only describe what is technically and economically within reason. There are several items, however, that were not considered in the calculation that will affect these costs somewhat. In this section some of the more important points are briefly discussed.

In calculating the costs of conversion to natural gas and electricity the possibility was ignored that new transmission and distribution equipment would be needed. This also holds for the conservation case, since natural gas freed by conservation would need to be delivered to sites formerly using fuel oil, and it is likely that new transmission and distribution facilities would be needed for some of those locations. A transmission and distribution operating cost for all the natural gas conversions was included but this is not likely to cover new construction where it is needed.

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[22] *Building a Sustainable Future,* op. cit., pp. 5 and 6.

*By using the 1990 EIA forecast rather than the 1990 SERI projection as the starting point, we have compressed some of the savings calculated by SERI. They assumed that much of the savings would occur between 1980 and 1990 with a result that their 1990 projection of fuel oil use is considerably below the EIA forecast. Our calculation does not change the net savings but only the period in which they could occur.

*Adjusted to reflect savings not accounted for by OTA's choice of base case.

[23] Ibid.

Similarly, the electricity made available by conservation may not be able to substitute for oil-fired capacity without the construction of new transmission lines. In a previous OTA study on solar energy,[24] the construction and operation costs of both electric and natural gas transmission and distribution systems were calculated. Using those values updated to 1980,[25] it was found in the worst case—electricity used to replace oil for heat in buildings—that the cost of oil replaced should be increased by about 20 percent. In all other cases the adjustment is less than 10 percent under the unlikely assumption that *all* the replacement energy requires new transmission and distribution facilities.

Another point concerns the choice of conservation estimates. The SERI study is the most optimistic of several analyses which attempt to calculate the potential for conservation under least cost conditions. The calculations in the SERI study, particularly for buildings, are based on the most complete analysis to date of the thermal characteristics of buildings, and include extensive experimental data. Therefore, these engineering and cost estimates can be considered as attainable.

Though the SERI calculations were used, it is not explicitly or implicitly claimed that SERI conservation targets will be reached. In an OTA study on building energy conservation recently completed it is estimated that only about 40 percent of the targets will be reached under current conditions.[26] A number of economic constraints and choices—including restrictive financial conditions, uncertainty of results, and high owner discount rates—will reduce the probability that these goals can be met. Even though it was not necessary to use the entire SERI estimate of savings to achieve OTA's hypothetical goal of eliminating stationary fuel oil use, more than two-thirds was still required. Therefore, while it is technically possible to eliminate all stationary fuel oil use through conservation, this is not likely to happen under current conditions.

The final point concerns conversion of oil-fired electric generation capacity to coal. Although the high end of the range of estimates for conversion costs was used, in some instances even this will be insufficient. There will be sites where conversion is impossible because of lack of coal storage facilities or inadequate coal transportation, or where excessive derating of the boiler would be necessary. In such cases, it will make more sense to retire the plant and replace it with new capacity built elsewhere. For these cases, the replacement cost will equal the cost of new capacity, including any needed transmission costs. It should be expected, however, that new coal or nuclear generation will have a much higher capacity factor than current oil generation because of the former's lower cost of producing energy.

It should be remembered, however, that the load profile will dictate the capacity factor to a great extent. With the large amount of capacity under discussion, it can be expected that there will be sufficient load diversity so that power transfers between regions will allow for an increase in capacity factor to a level that now exists for coal-fired powerplants (about 57 percent).

The possibility of power transfers was assumed and accounted for in the calculation by assuming the 57-percent capacity factor. The result is that less capacity is needed to replace the electricity produced by the oil-fired generation that is expected to be on-line in 1990. To some degree this capacity reduction will take care of some of the site-specific problems described above.

Another point to be considered is whether coal-fired electricity will be less expensive than that generated from residual fuel oil in the 1990's. Because of the continuing decline in crude oil quality[27]—i.e., lower gravity—it will be increasingly more costly to refine this oil up to the point where no residual oil remains. Currently, the average cost of converting residual fuel oil to middle distillates and gasoline is about $10,000 to $14,000/bbl/d.[28] The marginal cost, however, is much higher and will grow as more and more residual oil is transformed and as the crude oil feed becomes heavier.

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[24] *Application of Solar Technology to Today's Energy Needs, Vol. 1*, OTA-E-66 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1978), p. 140.

[25] *Oil and Gas Journal*, Aug. 10, 1981, p. 76.

[26] *The Energy Efficiency of Buildings in Cities*, OTA-E-168 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, March 1982).

[27] *Oil and Gas Journal*, Apr. 20, 1981, p. 27.

Consequently, it is possible that it would be cheaper to use the residual oil directly in boilers, as it is used now, and produce the lighter fuels from oil shale or by way of methanol from coal. To reach that point, residual fuel oil would have to be priced below coal as a boiler fuel because the residual oil would have no other market. No attempt was made to determine when or to what extent this may occur.

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[28] *An Analysis of Potential for Upgrading Domestic Refining Capacity*, op. cit.

SUMMARY

Elimination of fuel oil use in the stationary sectors (buildings, industry, electric utilities) appears to be technically plausible by 2000. The cost for either the conservation or fuel-switching scenario would be high. As shown, the total cost for the 1990-2000 period would be about $225 billion to $230 billion to eliminate the 2.6 MMB/D forecast still to be in use by 1990. These costs are consistent with estimates for synthetic fuels production and automobile efficiency improvement that would produce about the same amount of oil.* In addition, reduction from current use of 4.4 MMB/D to the 1990 level will also require several tens of billions of dollars. As noted earlier, the 1980-90 costs were not taken into account in the calculations.

Uncertainties about these estimates for stationary fuel oil elimination by conversion arise from changes in powerplant construction costs, in coal prices, in the cost of producing natural gas from tight sands, and in the discovery rate of new natural gas. All or any of these could cause significant swings in the cost of displacing oil, most likely upward. In the absence of information about these uncertainties, the estimates given here, which represent the best analyses to date, can be considered as reasonable. Similarly, for conservation, uncertainties about the conservation potential of buildings exist which can only be cleared up as more and more buildings are actually retrofit. Preliminary audits of buildings already retrofitted have indicated a range of energy savings from 80 percent less than predicted to 50 percent more.[29] The sample for this measurement was small, but it does indicate the level of uncertainty.

The estimates that were derived are plausible targets. They are not forecasts or even necessarily desirable goals. That will have to be decided within the context of all the economic choices possible and within the country's policy objectives about oil imports.

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*See ch. 5, p. 139; ch. 6, p. 172.

[29] *Energy Efficiency of Buildings in Cities*, op. cit.

Chapter 8

Regional and National Economic Impacts

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Chapter 8

Regional and National Ecomomic Impacts

INTRODUCTION

This chapter examines the types, timing, and distribution of economic impacts associated with both development of a synthetic fuels industry using national coal and oil shale resources, and improved automobile fuel efficiency. Identifying and assessing these impacts are difficult because: impacts are not distributed evenly in time or across regions, so that people may not receive benefits in proportion to the adverse consequences they experience; impacts are not translatable into directly comparable terms (e.g., dollars); the evaluation of impacts is subjective, based on perceptions of the uncertain benefits and costs of new technologies; and impacts are cumulative and may be difficult to monitor or attribute solely to a particular technology choice.

This chapter assesses the broad economic impacts of synfuels and changes in auto technology. Chapter 9 further analyzes employment effects and discusses other social impacts of these technological developments. Decisions about synfuels and making cars more efficient will require tradeoffs in terms of energy use, economic growth, and social welfare and equity. There will be both beneficial and adverse social consequences for the Nation as it moves towards energy independence.

ECONOMIC IMPACTS OF AUTOMOTIVE CHANGE

Overview

The economic impacts of improving automotive technology result primarily from two factors: the large investments that will be required for associated capacity, and changes in the goods and services purchased by the auto manufacturers. Large investments increase financial risk, exhaust profits, and influence the ability of firms to raise outside capital. Changes in goods and services used by manufacturers affect suppliers and, in turn, local economies. As automotive fuel economy increases, the structure and conduct of the auto industry and the relationship of the domestic auto industry to the general economy change. Radical increases in demand for fuel economy, induced either by changes in consumer preferences or by Government mandates, would lead to greater industry change, most likely in the form of acceleration or exacerbation of current trends.

Changes in the auto industry stem from both technological developments and new market trends, including strong competition from foreign manufacturers. Large increases in demand for fuel economy, and for small cars relative to large cars, encourage the industry to improve the fuel economy of all car classes and to invest in the production of small cars. These activities help domestic manufacturers to satisfy relatively new demands, but at the cost of diminished profits during at least the short term. Profits can fall when manufacturers prematurely write off large-car and other capacity investments and change their pricing strategies to replace large-car profits with small-car profits.

Meanwhile, manufacturers lose money when sales of their least efficient models decline. High fixed costs and scale economies make their profitability vulnerable to sales declines of even a few percent. Profits would therefore also fall if domestic manufacturers lost market share to foreign firms. Future opportunities to gain market share and profits will be limited by slowing market growth.*

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*The U.S. auto market is nearly saturated (there were 0.73 cars for every licensed driver in 1979, according to the Motor Vehicle Manufacturers Association) and the U.S. population is growing slowly. Therefore, auto sales will grow at lower rates than in past decades, probably averaging 1 to 1.5 percent per year.

Manufacturing Structure

The U.S. automotive industry includes three major manufacturers—General Motors (GM), Ford, and Chrysler—plus a smaller manufacturer, AMC (now almost half-owned by Renault, a French firm) and some very small specialty car manufacturers. The three major manufacturers have historically been characterized by moderate levels of vertical integration and broad product lines that include trucks and other vehicles as well as automobiles. During the past few decades, GM's operations have been the most extensive both vertically and horizontally; Chrysler's have been the least extensive.

Because of the high costs of production change, U.S. auto manufacturers are becoming less vertically integrated, relying increasingly on suppliers to make components and other vehicle parts. For example, the Department of Transportation (DOT) reported that in late 1980 alone, domestic manufacturers announced purchasing agreements with foreign suppliers for over 4 million 4-cylinder gasoline engines plus several hundred thousand units of other engines and parts. Reliance on outside suppliers, referred to as "outsourcing," relieves short-term spending pressures on manufacturers. By spending less initially to buy parts rather than new plants and equipment (in which to make parts), manufacturers can afford to make more production changes while exposing less cash to the risk of financial loss due to limited or volatile consumer demands.

On the other hand, outsourcing may cause manufacturers to lose control over product quality. Also, manufacturers may incur higher vehicle manufacturing costs in the longer term because the price of purchased items includes supplier profits as well as production costs. Because of more severe financial constraints, Ford and Chrysler tend to rely on suppliers more than GM. In the future, all domestic manufacturers may outsource more from domestic suppliers, foreign firms, or foreign facilities owned by domestic manufacturers as a means of reducing capital investments and thus short-term costs.

Manufacturers are consolidating their operations across product lines and engaging in joint ventures, primarily with foreign manufacturers. While there appears to be no up-to-date source of data aggregating these changes, trade journals and the business press report that American firms are sharing production and research activities with foreign subsidiaries, with foreign firms in which they have equity (Ford with Toyo Kogyo, GM with Isuzu and Suzuki, Chrysler with Mitsubishi and Peugeot, AMC with Renault), and with other foreign firms. Joint ventures are also increasingly common between non-American firms, which have historically been highly interconnected.

Cooperative activity among auto firms worldwide is likely to grow. Many firms will be unable to remain competitive alone, because of the growing costs and risks of improving automotive technology and increasing competition in markets around the world. The quickest way for U.S. manufacturers to respond to a mandated or demand-induced fuel economy increase would be to use foreign automotive concepts directly, by licensing designs, assembling foreign-made automobile kits, or marketing imported cars under their own names. GM and Ford, for example, assemble Japanese-designed cars in Australia and AMC sells Renaults in the United States.

Domestic companies can make profits by merely selling foreign-designed cars. They can gain additional manufacturing profits without risking additional capital if they sell cars made by companies in which they have equity. Cooperative activity (and, in the extreme, mergers and acquisitions) allows firms to pool resources, afford large investments in research and development (R&D) or in plant and equipment, gain scale economies, and spread large financial risks. It is consistent with the reduction in the number of autonomous auto producers widely predicted by industry analysts.

Although the number of automotive manufacturing entities is declining worldwide, there may be continued growth in the number of firms producing and selling in the United States. Already, Volkswagen produces cars in Pennsylvania and is building a plant in Michigan; Honda is planning to build cars in Ohio; and Nissan is building a light truck plant in Tennessee. There are now about 23 different makes of foreign cars sold in the United States, excluding "captive imports" sold under domestic manufacturers' nameplates (e.g., the Plymouth Colt, which is made by Mitsubishi).[1] Manufacturers of captive imports, including Isuzu and Mitsubishi, are already preparing to enter the U.S. market directly.

Manufacturer Conduct

U.S. auto manufacturers are fundamentally altering their product, production, and sales strategies as automobile technology and consumer demand change. Several changes in product policy include the following.

First, the number and variety of models is falling. The highest number of models offered by domestic manufacturers was 375 in 1970; 255 were offered in 1980.[2] Manufacturers might sharply reduce the number of available models to increase fuel economy quickly, by producing relatively efficient models on overtime and ceasing production of relatively inefficient models.

Second, while cars of all size classes are shrinking in number, small cars are becoming more prominent in number, share of capacity, and contribution to revenues relative to large cars. Recent changes in price strategy have led to smaller profit differentials by vehicle size and higher absolute and relative small-car prices. As individual models become more alike in size, manufacturers will differentiate models by visible options and design.

Third, manufacturers may introduce new, oil-conserving products such as very small "mini" cars (e.g., GM's P-car and Ford's Optim projects) and vehicles powered by electricity as well as alternating fuels.

Cost-reducing alterations to the physical and financial characteristics of individual firms—widely reported in trade journals, the business press, and company publications—help manufacturers adjust to declines in sales and profits and growing investment requirements. Cost-cutting efforts include reductions in white-collar employment and elimination of relatively inefficient or unneeded capacity. During the last couple of years GM, Ford, and Chrysler have sold or announced plans to sell several manufacturing and office facilities. One investment analyst estimates that sales of assets may have provided over $600 million to GM and Ford during 1981.[3]

Efforts to reduce long-term costs focus on measures to improve productivity and reduce labor costs per unit. To improve productivity, manufacturers (and suppliers) are already investigating and beginning to use new types of equipment, plant designs, and systems for materials handling, quality control, and inventory management. Industry analysts and firms also expect that improved coordination between management and labor, vendors, and Government will be important means for improving productivity and competitiveness. Finally, manufacturers maintain that reductions in hourly labor costs (wages and/or benefits) are essential for making U.S. cars competitive with Japanese cars. Whether, when, and how much labor costs are lowered depends on negotiations between manufacturers and the United Auto Workers union.

Another cost-cutting measure is reduction in planned capital spending. Spending cutbacks affect firms differently, depending on their context. For example, Chrysler reduced 1980 planned capital spendings by $2 billion, halting a diesel engine project and others.[4] GM has announced cutbacks that take the form of spending deferrals and cancellations of planned projects (with little effect on immediate cash flow, however).

Another factor which complicates the evaluation of cutbacks is that U.S. projects abroad are, and could be, used to supply the U.S. market. Foreign projects are relatively cheap where foreign partners or foreign governments share in or subsidize investments. Cost-cutting efforts are consistent with growth in the share of U.S. auto investment and production abroad, because facilities in Central and South America, Asia, and in parts of Europe generally produce at lower costs and sell in home markets that are more profitable than the U.S. market.

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[1] Automotive News, *1981 Market Data Book* (Detroit, Crain Communications, Inc., Apr. 29, 1981).

[2] Maryann N. Keller, "Status Report: Automobile Monthly Vehicle Market Review" (New York: Paine, Webber, Mitchell, Hutchins, Inc., February 1981).

[3] Maryann N. Keller, personal communication, 1981.

[4] *Ward's Automotive Reports*, June 15, 1981.

Some analysts believe that if extreme pressures were placed on U.S. manufacturers to make sizable investment in brief periods of time, Ford and GM (at least) would reduce U.S. production in favor of foreign production (Chrysler has divested foreign facilities to obtain cash). U.S. manufacturers and suppliers are already operating with high fixed costs, large investment requirements, weak demand, and labor costs higher than foreign competitors. If there are sharp increases in fuel economy demand, or if there are other sources of growth in perceived investment requirements—without offsetting changes in manufacturing and demand/market share—these developments might give auto firms additional incentives to curb, if not abandon, auto production in the United States. If U.S. production were curtailed, it would affect production of new, very efficient small cars while U.S. production of larger and specialty cars would probably continue. Large and specialty cars are characterized by consumer demand that is relatively insensitive to price and in many cases limited to U.S. car buyers.

Other Firms

Suppliers

Automobile suppliers manufacture a wide variety of products, including textiles, paints, tires, glass, plastics, castings and other metal products, machinery, electrical/electronic items, and others. Changes in the volumes of different materials used to produce cars and the ways in which cars are produced are changing the demands on suppliers. In the near term, for example, GM predicts that the average curb weight of its cars will fall 21 percent, from 3,300 lb in 1980 to about 2,600 lb in 1985, with up to 67 percent more aluminum, 48 percent more plastics, and 30 percent less iron and steel, by weight. Rubber use will also fall. GM predicts that steel will comprise a relatively constant proportion of car weight, while the proportion of iron will fall and aluminum and plastics proportions may even double by 1985[5] (see table 58).

Changes in demands for materials and other supplies create pressures on traditional suppliers to close excess capacity and invest to develop or expand capacity for new or increasingly important products. They also create new business opportunities for firms whose products become newly important to auto manufacturers, such as semiconductor and silicone producers. The degree of hardship on individual traditional suppliers depends on how much of their business is automotive and on their resources for change. Like the auto manufacturers, suppliers operate in the context of a cyclical market which can cause their cash flow to be unstable. Table 59 indicates the dependence of different supplier groups on automotive business as of 1980.

The steel and rubber industries have already been adversely affected by changing auto demands together with stronger import competition. Tire manufacturers have suffered with the rise in popularity of radial tires (which are replaced less frequently than bias ply tires and require different production techniques) and the fall in rubber use per vehicle. Between 1975 and 1980, over 20 tire plants (about one-third of the domestic total) were closed, one major tire manu-

Table 58.—GM's Major Materials Usage (per typical car, 1980 v. 1985)

	1980		1985	
Materials	Pounds	Percent total	Pounds	Percent total
Iron	500	15%	250-300	10-12%
Steel	1,900	58	1,450	56
Aluminum	120	4	145-200	6-8
Glass	92	3	80	3
Plastics	203	6	220-300	8-12
Rubber	88	3	88[a]	3[a]
Other	377	11	277	11
Total	3,300	100%	2,600	100%

[a] GM projects actual rubber use to be less than 88 lb in 1985.

SOURCE: General Motors Corp., reported in *Wards Automotive Reports*, Apr. 27, 1981.

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[5] "GM Sees Big Gain for Aluminum, Plastics in 'Typical' 1985," *Ward's Automotive Reports*, Apr. 27, 1981.

Table 59.—1980 Motor Vehicles (MVs) and Parts Supplier Trade

Industry	Percent of industry output for MVs and parts	Value of output for MVs and parts
Textiles	7+	$4 billion+
Wood products	2+	618 million+
Nonhousehold furniture	2.4	260 million
Paper and allied products	3	2.5 billion+
Chemical	4−	15 billion+
Plastics, synthetic rubber, and synthetics	6−	4 billion+
Paints and allied products	8+	900 million+
Tire and rubber products (OEM)	13	4 billion+
Glass	11−	1.3 billion
Steel furnaces, foundries, and forgings	21−	24.6 billion
Aluminum and aluminum products	14.6	4 billion+
Copper and other nonferrous metal products	11−	6 billion+
Metal products and machine shop products	13−	22 billion
Metalworkings and industrial machinery	5.6	8 billion+
Service industry machinery	12	3 billion
Electrical and electronic equipment	5.2	8 billion
Scientific and controlling instrument	7.5	900 million

NOTES: "+" means "greater than" and "−" means "less than." "OEM" stands for "original equipment manufacturer."

SOURCE: The Automotive Materials Industry Council of the United States.

facturer (Mansfield) declared bankruptcy, and another (Uniroyal) suffered severe financial problems (see fig. 18). Several steel plants were closed during the same period. In both industries, additional plant closings and continued import competition are likely in the 1980's, although the elimination of excess and inefficient capacity is expected by Government and private analysts to leave these industries financially healthier.[6]

Machinery and parts suppliers also face import competition and product demand changes. A recent Delphi survey of auto suppliers conducted by Arthur Andersen & Co. and the Michigan Manufacturers Association (hereafter referred to as A&M) predicted that these suppliers will be investing together at least $2 billion per year in the 1980's, especially for new equipment (about 60 percent of total investment).[7] Machinery investments are needed both to make new types of supplied products and to help suppliers adapt to a shortage of skilled machinists. A recent study prepared for DOT by Booz-Allen & Hamilton describes the types and levels of investments associated with different types of auto activities on a new-plant basis (see table 60).[8]

Analyses by A&M, Government agencies, and industry analysts suggest that both appreciation of the types of supplier changes needed and ability to make those changes are greater among larger supplier firms than among smaller ones. Most supplier firms are small- and medium-sized, although a few large firms have large shares of the auto supply business. Among GM's total 32,000 suppliers in the United States, for example, only 4 percent have at least 500 employees while 52 percent have at most 25.[9]

Auto product change and market volatility are leading large suppliers, in particular, to diversify into nonautomotive products. For example, between 1978 and mid-1981 Eaton Corp., a major supplier, spent about $470 million to buy companies producing electronics, machinery, electrical parts, hydraulic systems, and other high-technology goods.[10] Large suppliers are also

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[6] U.S. Department of Commerce, *1981 U.S. Industrial Outlook* (Washington, D.C: U.S. Government Printing Office, 1981).

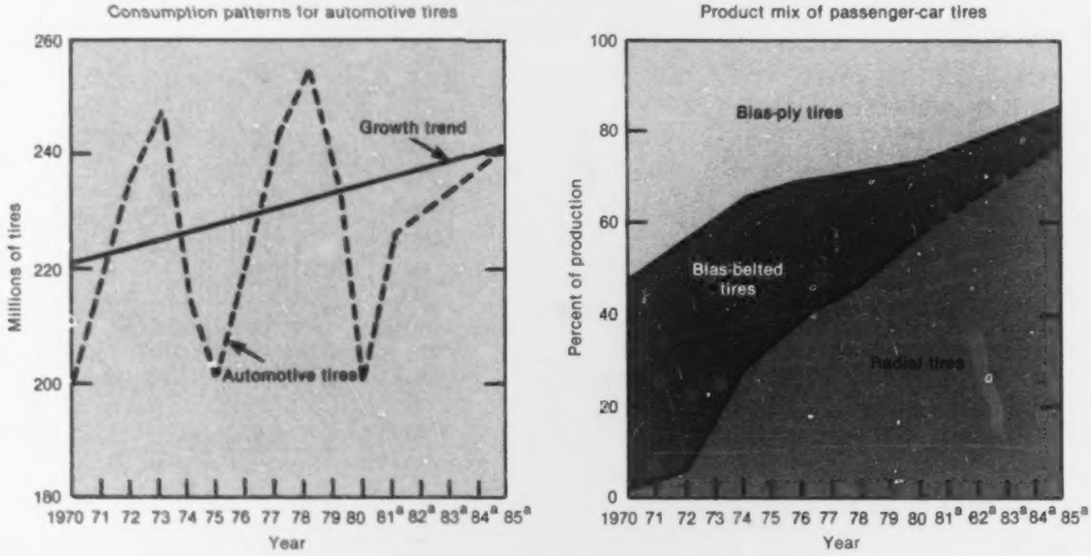
[7] Arthur Andersen & Co. and the Michigan Manufacturers' Association, "Worldwide Competitiveness of the U.S. Automotive Industry and Its Parts Suppliers During the 1980s" (Detroit: February 1981).

[8] Booz-Allen & Hamilton, Inc., *Automotive Manufacturing Processes* (Washington, D.C: U.S. Department of Transportation, National Highway Traffic Safety Administration, February 1981).

[9] "Supplier Conference, Ford/Europe Interview Underscore Threat," *Ward's Automotive Reports*, June 15, 1981.

[10] "Eaton: Poised for Profits From Its Shift to High Technology," *Business Week*, June 8, 1981.

Figure 18.—Tire Industry Trends



Consumption patterns for automotive tires

Product mix of passenger-car tires

[a] Estimated by Bureau of Industrial Economics.

SOURCE: Trade Association data.

[a] Estimated by Bureau of Industrial Economics.

SOURCE: Trade Association data.

Major tire manufacturer earnings fall,
July 1979 to June 1980, as the table below shows:

Company	Change in earnings
Armstrong	+ 12.1%
Cooper	negative (loss)
Dunlop	negative (loss)
Firestone	negative (loss)
General	negative (loss)
Goodrich	+ 11.2%
Goodyear	– 40.8%
Mohawk	negative (loss)
Uniroyal	negative (loss)

SOURCE: U.S. Department of Commerce, Bureau of Industrial Economics, *1981 U.S Industrial Outlook*, January 1981.

strengthening their international operations, diversifying away from the U.S. market. Small- and medium-size firms are likely to follow auto manufacturers in undertaking joint R&D and production ventures, while mergers and acquisitions and even closings or bankruptcies are likely.* The A&M survey predicted that decline in the numbers of suppliers will lead to increased vertical integration among suppliers, while strong import competition and other market changes will motivate increases in supplier productivity.

Sales and Service

Other segments of the auto industry include dealers and replacement part and service firms. The latter group, which serves consumers after they buy their cars, is called the automotive aftermarket.

Dealer sales activities are not necessarily affected by changing auto technology per se. Sales depend on consumer income and general eco-

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*According to Dun & Bradstreet, transportation equipment firms, primarily including auto suppliers, suffered financial failure at a rate of 101 per 10,000 in 1980, as compared with a rate of 42 per 10,000 for all manufacturers.

Table 60.—Examples of Supplier Changes and Associated New Capacity Investment[a]

Characteristics	Approximate capital requirements for property, plant, and equipment
Foundries	
90 percent of auto castings use iron, 92 percent of which are sand cast, and auto manufacturers operate about 20 percent of U.S. sand casting capacity	$21 million (typical independent die cast foundry producing 15,000 tons/year)
Downsizing and production of smaller parts generates excess capacity	
Materials substitution reduces sand casting with iron and increases die casting with aluminum	
Metal stamping	
Autos have had up to 3,000 stampings and auto manufacturers produce about 60 percent of all stampings by weight	$67 million (typical captive plant producing stampings for 175,000 cars/year; independent plants are smaller and cheaper)
Materials substitution decreases carbon steel, increases high-strength steel and aluminum for stampings	
Plastics processing	
Injection molding	$31 million (typical plant producing 65 million lb parts/year)
Compression molding	$43 million (typical plant producing 60 million lb compound/year
Reaction injection molding	$19 million (typical plant producing 30 million lb parts/year)

[a] Figures for completely new facilities.

SOURCE: Booz-Allen & Hamilton, Inc., *Automotive Manufacturing Processes*, prepared for the Department of Transportation, National Highway Traffic Safety Administration, February 1981.

nomic conditions (including the availability of credit), demographic conditions (including household size), the price of fuel, and vehicle price and quality attributes. Although consumers have responded to recent gasoline price increases by demanding relatively fuel-efficient cars, the experience of the recent recession illustrates that overall sales levels in a given year are primarily determined by consumer finances and not by vehicular technology.

There are about 300,000 automobile repair facilities in the United States[11] (see table 61). New automobile technology affects them because automobile design and content are changing. For example, problems in new, computer-controlled components will be diagnosed with computerized equipment, and plastic parts will be repaired with adhesives rather than welding. Components are more likely to be replaced than repaired on the vehicle or even at the repair shop. While automobile service firms will have to invest in new equipment and skills to service new cars, continued service needs of older cars may ease the transition.

Table 61.—1980 Auto Repair Facilities

Type of facility	Quantity
Dealers	26,000
Auto repair shops (independent and franchised)	170,000
Tire—battery—accessory outlets	18,850
Other auto and home supply stores	1,860
Gasoline stations	70,000
General merchandise stores	3,500
All others	1,430
Total	292,240
Total including facilities selling only parts, accessories	331,090

SOURCE: *Wards Automotive Reports*, Apr. 6, 1981.

However, the concurrent operation of very different types of cars requires firms to double their parts inventories to service both types. The dollar value of parts and the frequency of repairs are also likely to differ between new and old car types. Manufacturers are attempting to curb service cost growth by designing cars for easy servicing. For example, the Ford Escort and Lynx and the Chrysler K and Omni/Horizon cars were designed so that servicing during the first 50,000 miles would cost less than $150.[12]

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[11] "Auto Repair Facilities Total 300,000," *Ward's Automotive Reports*, Apr. 6, 1981.

[12] Francis J. Gaveronski, "Ford's New Escort, Lynx Designed for Easy Service," *Automotive News*, May 19, 1980, and "Chrysler K-car to Stress Ease of Diagnosis, Repair," *Automotive News*, June 16, 1980.

The effects of new repair and service practices on the structure of the aftermarket are uncertain. During the past decade, repair and service activity shifted from dealers to service centers run by general retailers (e.g., Sears) and tire retailers (e.g., Firestone) and to specialized franchised centers for tune-ups, body work, or component service (e.g., AAMCO Transmissions and Midas Muffler). Both of these trends help to moderate service cost increases because of scale economies in planning and management. However, the intimate and advance knowledge of new technologies held by manufacturers is likely to help dealers regain repair and service business. While dealers now perform about 20 percent of auto repairs, they are expected to gain a greater share by the mid-1980's. Meanwhile, scale economies in advertising and inventory management may promote consolidation among parts firms.[13]

Prospects

Further financial strain on the domestic auto industry is not likely to lead to financial failure of major manufacturer and supplier firms (except perhaps Chrysler, but Government intervention makes its future hard to predict). However, the continued viability of many smaller auto suppliers is becoming especially uncertain because automotive technology changes make products and capacity obsolete. While the industry may continue to contract, "collapse" of its leading firms is not likely because major and even intermediate-sized firms can make at least partial adjustments to automotive market changes; adjustments are already under way. Reduction in the U.S. activities of domestic firms and failure or contraction of smaller firms would, nevertheless, severely affect employment and local economies.

In contemplating the future of the industry it is important to appreciate what financial failure means. In a technical sense, businesses fail when they are unable to make scheduled payments. If this inability is temporary, firms can usually negotiate with creditors or seek protection from bankruptcy courts to relieve immediate creditor demands. In many cases, bankrupt firms are successfully reorganized, structurally as well as financially. However, some firms find that the stigma of bankruptcy makes producing and selling especially difficult.* If selling a firm's assets generates more value than using them for production by the firm, the firm is fundamentally unviable, and there are financial and economic grounds for liquidating it.

Barring Government support or merger, Chrysler is the large automotive firm most likely to fail if viability in the U.S. market entails large investments that it cannot afford. AMC has been at least temporarily rescued by the French Government-backed Renault. Because Chrysler's financial weakness has been known for years, the magnitude of the potential social and economic effects of its failure has been diminishing as Chrysler has cut back its operations and suppliers have reduced their dependence on Chrysler as a customer.

In mid-1979, when Data Resources, Inc., prepared for the U.S. Department of the Treasury a simulation of the macroeconomic effects of a Chrysler bankruptcy and liquidation, it found that only temporary macroeconomic instability was likely to result, although 200,000 people might be permanently unemployed. Dependence of workers and businesses on Chrysler has diminished since that simulation was done, although small firms for which Chrysler is a primary customer remain vulnerable. If Chrysler were to liquidate, its exit from the U.S. market would provide opportunities to domestic and foreign manufacturers to expand market share and purchase plant and equipment at relatively low cost. This could relieve financial pressures on Ford and GM.

While contraction of the U.S. auto industry may result in fewer, healthier firms, employment and local economies will suffer.** Loss of jobs will result predominantly from supplier-firm difficulties. Unemployment of auto industry workers may also affect the performance of the national economy. Unemployment causes a more than proportionate decline in aggregate production, because slack demand reduces average hours per worker, output per worker, and entry into the labor force. The reduction in disposable personal income (DPI) because of unemployment reduces personal consumption spending. Reduced personal consumption (and business fixed investment) spending reduces gross national product (GNP), causing DPI to fall, and so forth. Both personal and corporate tax revenues decline, while transfer payments to unemployed workers and economically depressed communities rise.

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[13] Maryann N. Keller, "Status Report: Auto Parts Industry Automotive Aftermarket Quarterly Review" (New York: Paine, Webber, Mitchell, Hutchins, Inc., July 29, 1980).

*When Lockheed and Chrysler appealed for Government aid, they both argued that their customers would not buy from firms in bankruptcy. This is more likely to be a problem for automobile (or aircraft) manufacturers than for their suppliers, given the difference in size of customer purchase and producer liability.

**Also, change in the amount of U.S manufacturer operations in Canada (not considered "foreign") could imply violation of our obligations under the Automotive Products Trade Act agreements with Canada.

The national economy can better adjust to auto industry trauma than local and regional economies because the national economy is more diversified, and because, over time, national economic sensitivity to auto industry problems has been diminishing. Since World War II, manufacturing employment in the Midwest (and Northeast) has been declining as a percent of national manufacturing employment; it has declined in absolute volume since 1970 because job opportunities have not been growing, foreign and domestic firms have located facilities in other regions, and other industries primarily located elsewhere have been growing in their importance to the economy.* In this context of structural change, the 1975 recession seems to have been a turning point for traditional Midwest manufacturing, accelerating a trend of decline that was further aggravated by the 1979-80 oil crisis and recession.

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*Electronics, computing equipment, chemicals and plastics, aerospace equipment, and scientific instruments have been the leading growth industries in the postwar period. These industries are both outlets for diversification by auto-related firms and competitors to traditional auto-related firms in automotive supply.

ECONOMIC IMPACTS OF SYNFUELS

Because large blocks of capital are required for synfuels projects, they will be visible centers of economic activity even from a national viewpoint and, in fact, for people outside of the synfuels industry, the economic costs and benefits of synfuels may be more easily understood in terms of regional and national impacts.

Despite the absence of commercial experience, an outline of the synfuels industry emerges with comparisons to coal mining, conventional oil and gas production, chemicals processing, and electric power generation. By itself, this new industrial organization is an important economic impact, as it changes the way economic decisions are made regarding the supply of premium fuels. Furthermore, along with the technologically determined menu of resource requirements, industrial organization determines the major regional and national economic impacts of synfuels deployment.

Potential regional and national economic impacts are then explored through comparisons of aggregate resource demands and supplies. Since plans call for very large mines and processing plants, and perhaps many construction projects in progress at once, the emphasis is on potential bottlenecks which could delay deployment schedules and drive up project costs. If severe resource bottlenecks do occur, the resulting inflation in the prices of these resources will spread through the economy, driving up prices and costs for a broad range of goods and services.

These resource costs add up in the next section of this chapter to financial requirements for projects and for the industry as a whole. To the extent that the Federal Government does not intervene, individual firms must compete in financial markets with all other products and all other firms for limited supplies of debt and equity capital. With the important exception of methanol and ethanol from biomass,* the large scale and long leadtimes of synfuels projects may make it difficult to raise capital, especially during the next decade, when important technological uncertainties are likely to remain. Federal subsidies or loan guarantees will speed synfuels deployment—but only by reducing capital available to other types of investments, by reducing other Federal programs, by increasing taxes, or by increasing the Federal deficit. Depending on general economic conditions, each of these different market interventions may be inflationary.

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*Ethanol from biomass is not included in this discussion because with current technology its potential production is limited by the availability and price of feed-grain feedstocks. However, if economic processes for converting ligno-cellulose into ethanol are developed, ethanol could compete with methanol as a premium fuel from biomass.

Each of these areas of regional and national economic impacts—industrial structure, potential resource bottlenecks, finance capital, and inflation as related to synfuels development—is discussed below.

The Emerging Industrial Structure of Synfuels

Synfuels are fundamentally different from conventional oil and gas because they are manufactured from solid feedstocks and because synfuels economics may lead to the replacement of conventional fuels by methanol and low- or medium-Btu gas in the future. Liquids from coal and oil shale, the feedstocks with a natural resource base sufficient to fully displace petroleum in the long run, involve economies of scale which encourage ownership concentration. The methanol option, however, provides offsetting opportunities for large chemical firms to enter the liquid fuel business and, based on biomass feedstocks, it may also allow many small producers to supply local markets throughout the Nation.

The following discussion is broken down into the four stages of synfuels production. While this breakdown is convenient, it should be understood that several stages of production may be performed on the same site in order to minimize handling, transportation, and management costs.

Mining Coal and Shale

Mining for synfuels will closely resemble mining for any other purpose except that the mines dedicated to synfuels production will be relatively large.[14] It takes approximately 2.4 million tons of coal per year to fire an 800 MWe generator and about three times that much to feed a 50,000 barrels of oil equivalent per day (BOE/D) coal synfuels plant, and about four to eight times as much oil shale (by weight) for the same output of liquid fuel produced by surface retorting.*

Capital costs for development of a coal mine depend primarily on the depth and thickness of the coal seam. Average investment cost data can be misleading, since each mine is unique, but it takes about $60 of investment per annual ton of coal mined underground (1981 dollars). With coal preparation and loading facilities, investments at the mine site may approach $100 per annual ton, or about $750 million for capacity sufficient to supply a 50,000 bbl/d synfuels plant. Western surface mining may in certain cases be substantially less expensive.** Furthermore, substantial synfuels production may be achieved on the basis of existing excess mining capacity.***

In the absence of commercial experience, investment cost estimates are unavailable for shale mining. It is clear, however, that they can be either larger or smaller than for coal, depending on two opposing factors. First, investments costs could be much higher because of the low energy density of shale. Hence, much more material must be mined per barrel of oil equivalent. Second, shale investment costs could be lower because major shale resources lie in very thick seams (in some areas over 1,000 ft thick) and often relatively near the surface. Estimates for the first commercial shale project indicate that mining investments for a 50,000 bbl/d project may be substantially below $750 million.* Furthermore, if in situ retorting techniques fulfill optimistic expectations, shale mining could become relatively inexpensive as mining and retorting operations are accomplished together underground.

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[14] For an extensive discussion of mining techniques and costs, see *The Direct Use of Coal: Prospects and Problems of Production and Combustion*, OTA-E-86, (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1979), chs. III and IV.

*This range is determined by the Btu content of coal and shale and by the efficiencies of converting a Btu of solids into a Btu of finished liquid fuels. If we just compare shale oil and methanol (the two liquid synfuel options which are best understood and probably of least cost), conversion efficiencies are comparable, so the difference in feedstock rates is entirely a matter of the energy density of the feedstock. Coal has 16 to 30 MMBtu/T with Western coal typically on the lower end of the range. Shale, which is presently considered suitable for retorting, has 3.6 to 5.2 MMBtu/T. Hence, the ratio of shale to coal inputs can be as low as 4.2 and as high as 8.3.

**Investment cost data were obtained from National Coal Association. Federal surface mine regulations have increased investment requirements in increasing the equipment required to operate a mine and to reclaim land after coal has been removed, by increasing the amount of premining construction and equipment required to establish baseline data, and by extending the required development period.

***The National Coal Association estimates excess capacity at 100 million to 150 million tons per year. The low end of the range is calculated on the basis of the number of mines closed and the number of workers working short weeks. The high end of the range is calculated by comparing peak weekly production to average annual output per week.

Mine investment is important in project planning, but its share in total investment is still usually less than a third. (Notice that in the estimated investment costs for coal-based synthetics in ch. 8, the cost of the mine was not included. It is included in ch. 4 in the discussion of total investment costs.) Beyond actual costs, the activity of mining itself is important in the synthetic fuel cycle because of its previous absence in the U.S. oil and gas industry. In fact, the entire sequence of economic events associated with extraction of coal and shale contrasts sharply with the extraction of conventional petroleum and natural gas. The key difference is that oil and gas reserves must be discovered, with potentially large rewards for the discoverer, while the location and morphology of coal and shale resources have been known for a long time.

A wildcat driller, looking for an oil or gas deposit, can rent and operate a drilling rig with a relatively small initial investment. Since the most promising prospects have already been drilled in this country, exploration typically is a high-risk gamble and, although investment is small compared with development of resources, it can still require large sums of money in frontier areas such as deep water or the Arctic. The uncertainty is a deterrent to investment, but potentially large payoffs and special Federal tax incentives continue to attract large numbers of investors and large sums of capital.[15] Furthermore, the wildcatter can induce cooperation from landowners, local government officials, and any other powerful local interests by promising royalty payments, or at least a rapid expansion of local business activity, without serious environmental impacts. Only after a substantial reservoir has been discovered is it necessary to make relatively large investments in development wells, processing equipment, and pipelines.

In mining, there is nothing comparable to the opportunity and uncertainty of discovery wells. Most of the business parameters of a potential mine site are evident to the landowner and to all potential mining companies, which means that profit margins are generally limited by competitive bidding.

As discussed below, mines also typically employ more labor per million Btu of premium fuel produced than oil and gasfields[16] and they have many more adverse environmental impacts (e.g., acid drainage, subsidence, etc). For both reasons, interests external to the firm are more likely to oppose and perhaps interrupt mining operations. Investors realize such contingencies and see them as risks for which they expect compensation.

This discussion of relative payoffs and risks is by no means complete or conclusive, but it does suggest that private investors may exploit mining prospects for synfuels much more slowly than prospects for conventional oil and gas, or that investors will accept much greater risks with conventional oil and gas prospects because of the offsetting chances of striking it rich. Synfuels capacity could still expand rapidly, but probably not without very high profit incentives to reorient investors who have traditionally been in oil and gas exploration.

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*The Denver office of Tosco Corp. estimates that mine costs for the Colony project, which is the first shale project to proceed with commercial development, could be as low as $250 million. That particular site has the advantage that large-scale open pit mining equipment can be used in an underground mine, since the seam is horizontal and the mine can be entered via portals opened in a canyon wall. This means that the reclamation costs of a surface mine can be avoided as well as the costly mine shaft of a conventional underground mine. Furthermore, the site is propitious because there is virtually no methane trapped in the shale, so safety measures are minimal. In the future, mine costs as well as conversion costs may be held down by in situ liquefaction, but this technology remains unproven.

[15] In 1979, approximately $12.5 billion was invested in exploration for oil and gas in the United States. That includes (in billions), $5.4 for lease acquisition, $4.5 for drilling, $2.3 for geological and geophysical activity, and $0.3 for lease rentals. (See *Capital Investments of the World Petroleum Industry*, 1979, Chase Manhatten Bank, p. 20, and *Basic Petroleum Data Book*, American Petroleum Institute, vol. 1, No. 2, sec. III, table 8a). $12.5 billion is about 3 percent of total gross domestic investment ($387 billion). (See 1980 Statistical Abstract, p. 449.)

The oil and gas industry receives special tax treatment mainly in terms of expensing intangible expenditures of exploration, even though they are surely treated as capital expenses in corporate accounts.

[16] Although oil and gas has been closing steadily, in 1979 it took approximately 14,500 workers (miners and associated workers) to produce a Quad of coal and about 11,500 workers to produce a Quad of oil and gas. However, the labor intensity of mining for synfuels is actually 160 to 200 percent greater than for coal alone, since only about 50 to 60 percent of the energy in coal feedstock remains in the finished synfuel product. See 1980 Statistical Abstract, p. 415, for employment data and *1980 Annual Report to Congress*, Energy Information Administration, p. 5, for production data. See note 2, ch. 9 for further discussion of labor productivity.

Conversion Into Liquids and Gases

During the second stage of production, solid feedstocks are converted into various liquids and gases. Current synfuels project plans indicate that coal or shale conversion plants will resemble coal-fired electric power stations in the sense that both convert a large volume of solid feedstock into a premium form of energy. They will resemble chemical processing (in products such as ammonia, ethylene, and methanol from residual oil or natural gas) and petroleum refining facilities in their use of equipment for chemical conversions at high temperatures and pressures.*

Of the $2 billion to $3 billion (1981 dollars) required overall for a 50,000 BOE/D shale project, between one-third and one-half goes into surface retorts which decompose and boil liquid kerogen out of the shale rock. A larger fraction of total project costs is required to obtain methanol from coal, but with subsequent avoidance of the upgrading and refining costs.** In general (but with the exception of in situ mining shale), the conversion step alone requires investments comparable to a nuclear or coal power station of 1 GWe capacity or to outlays for a 200 to 400,000 bbl/d petroleum refinery.[17]

Factors other than economy of scale dominate the economics of syngas production, as demonstrated by the existence of many small gasification plants across the country.[18] Two factors account for this. First, gasification is only the first stage in the production of either methane or methanol, so costs of the second stage can be avoided and system engineering problems are less complex and more within the technical capabilities of smaller users. Airblown gasifiers involve the least engineering, since they do not require the production of oxygen, but only certain onsite end users such as brick kilns can use the low-Btu gas. The second reason involves transportation and end-use economics.

In many industrial applications, natural gas (methane) has been the preferred fuel or feedstock, but medium-Btu gas is an effective substitute in existing installations because it requires relatively minor equipment changes. Either low- or medium-Btu gas may be used in new installations, depending on the industrial process and site-specific variables. However, since these methane substitutes cannot be transported over long distances economically, conversion facilities must be located near the end users.

The size of the conversion facility is therefore determined by the number and size of gas consumers within a given area, and this often dictates conversion plants that are small in comparison with a 50,000 bbl/d liquid synfuels plant. Consequently, industrial gas users may choose to locate near coalfields in order to produce and transport their own gas or to contract from dedicated sources. Either approach assures security of supply and availability over many years.

Upgrading and Refining of Liquids

As discussed in chapter 6, raw syncrudes from oil shale and direct liquefaction must be upgraded and refined to produce useful products. Technically, these activities are quite similar to petroleum refining, and this affords a competitive advantage to large firms already operating major, integrated refineries. This bias toward large, established firms is reinforced in the case of direct coal liquids by the apparent cost reduction if upgrading and refining are fully integrated with conversion, thus making it difficult for smaller firms to specialize in refining as some do today. Upgraded shale oil, on the other hand, is a high-grade refinery feedstock that can be used by most refineries.

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*Refineries typically use lower pressures than chemical plants and lower than what is expected for synfuels conversion.

**For a breakdown of methanol costs, see ch. 8.

[17] As discussed in ch. 8, all synfuels capital cost estimates are very uncertain because none of these technologies has been used commercially. Furthermore, engineering cost estimates available to OTA typically do not clearly differentiate costs by stages of production. Nevertheless, the conversion step, going from a solid feedstock to a gas or a liquid product, is undoubtedly the most expensive single step in synfuels production. For presentation of costs for electric power stations see *Technical Assessment Guide*, Electric Power Research Institute, July 1979.

[18] See National Coal Association, "Coal Synfuel Facility Survey," August 1980, for a listing and discussion of between 15 to 20 low-Btu gas facilities coupled with kilns, small boilers, and chemical furnaces.

Downstream Activities: Transportation, Wholesaling, and Retailing

As long as synthetic products closely resemble conventional fuels, downstream activities will be relatively unaffected. However, medium- or low-Btu gas and methanol are sufficiently different to require equipment modifications, and they may be sufficiently attractive as alternative fuels to induce changes in location of business and structure of competition.

Depending on the market penetration strategy, methanol may be mixed with gasoline or handled and used as a stand-alone motor fuel. As a mixture, equipment modifications will involve installation of corrosion-resistant materials in the fuel storage and delivery system. As a stand-alone fuel, methanol may have its own dedicated pipeline and trucking capacity and its own pump at retail outlets, and auto engines may eventually be redesigned to obtain as much as 20 percent added fuel economy, primarily by increasing compression ratios and by using leaner air-fuel mixtures when less power is required.[*]

If firms currently producing methanol for chemical feedstocks should enter fuel markets,[19] drivers stand to gain from the increased competition among the resulting larger number of major fuel-producing companies and by competition between methanol and conventional fuel. Furthermore, with coal-based methanol providing a critical mass of potential supply, drivers across the Nation may be able to purchase fuel from small local producers (using biomass feedstocks), a situation which has not obtained since the demise of the steam engine.

Medium- or low-Btu gases are effective substitutes for high-Btu gas (methane) but, as discussed above, their relatively low energy density prohibits mixing in existing pipelines and generally restricts the economical distance between producer and consumer (the lower the Btu content the shorter the distance). Hence, deployment of these unconventional gases will require dedicated pipelines, relocation of industrial users closer to coalfields, or coal transport to industrial gas-users.

Conclusion and Final Comment

Massive financial and technical requirements for synthetic liquids from oil shale and coal encourage ownership that is more concentrated than has been typical in conventional oil and gas production. Large firms, already established in petroleum or chemicals, have three major advantages.

First, they can support a large in-house technical staff capable of developing superior technology and capable of planning and managing very large projects. Second, they can generate large amounts of investment capital internally, which is especially important during the current period of high inflation (inflation drives up interest on borrowed capital, making it much more expensive for smaller firms who must supplement their more limited internal funds).

Third, such firms already have powerful product-market positions where synthetic liquids must compete, so entry by new firms involves a greater risk that synthetic products cannot be sold at a profit.[*] The second and third advantages may be

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[*] See ch. 9 for further information about methanol vehicles.

[19] At the present time, approximately 1.2 x 10^9 gal barrels of methanol (11 x 10^6 BOE) are produced domestically, primarily from natural gas, and used almost exclusively as a chemical feedstock. See *Chemical and Engineering News*, Jan. 26, 1981.

[*] Predicting investment behavior is always difficult, but barring Federal policy to the contrary, the most likely group of potential investors are the 26 petroleum and chemical firms, each with 1981 assets of $5 billion or more (see list below). Seven chemical firms were included in this list primarily because they may be in a strong position to produce and market fuel methanol, based on their experience with methanol as a chemical feedstock.

Fortune, May 4, 1981, presents a listing of the 26 largest (in terms of total assets) petroleum and chemical firms: Exxon, Mobil, Texaco, Standard Oil of California, Gulf Oil, Standard Oil of Indiana, Atlantic Richfield, Shell Oil, Conoco, E. I. du Pont de Nemours,* Phillips Petroleum, Tenneco,* Sun, Occidental Petroleum, Standard Oil of Ohio, Dow Chemical,* Getty Oil, Union Carbide,* Union Oil of California, Marathon Oil, Ashland Oil, Amerado Hess, Cities Service, Monsanto,* W. R. Grace,* and Allied Chemical.* Asterisk indicates firm primarily in the chemicals industry.

This conclusion about the dominance of larger companies holds despite the fact that current synfuels projects planned or under study

(continued on next page)

nullified if several smaller firms can effectively band together into consortia, but it may be much more difficult for a consortium to build a technical staff which can develop superior technology and manage large projects during the next decade, when there will be many technical risks.

Ownership concentration is an important aspect of industrial organization in an economy organized on classical economic principles of anonymous competition, market discipline, and consumer sovereignty. Very large synfuels projects owned by very large energy corporations and consortia of smaller firms would not be anonymous, even from the viewpoint of the national economy, and they would have leverage to dictate terms in their input and output markets.

Conversely, once companies have made very large investments in new synfuels projects, they become visible targets for political action which might significantly raise costs or reduce output. Visible producers may not in fact allocate resources much differently than if there were only anonymous competitors, but at least the opportunity to manipulate markets exists where it would not otherwise—and just the appearance of doubt about the existence of consumer sovereignty can raise serious political questions.

The capital intensity of synfuels will also change the financial structure of the domestic liquid and gaseous fuel industry. Compared with investments in conventional oil and gas during the last 20 years, investment in synfuels per barrel of oil equivalent of productive capacity (barrels of oil per day) will increase by a factor of 3 to 5.[20] While all such calculations are of necessity very imprecise, the order of magnitude is confirmed by data contained in the 1980 Annual Report of Exxon Corp. As of 1980, Exxon's capitalized assets in U.S. production of oil and gas totaled $11.5 billion, and its average daily production rate (of crude oil and natural gas) was about 1.4 million BOE; so its ratio of capital investment to daily output was $8,200.[21] A 50,000 BOE/D synfuels plant at $2.2 billion implies a ratio more than five times larger ($44,000/BOE/D).

In other words, switching from conventional to synthetic liquids and gases amounts to a substitution of financial capital (and the labor and durable goods it buys) for a depleting stock of superior natural resources. A parallel substitution of investment capital for natural resources is occurring as conventional resources are increasingly hard or expensive to find and develop because of the depletion of the finite stockpile of natural resources.

As long as the United States could keep discovering and producing new oil and gas at relatively low cost, energy supplies did not impose serious inflexibilities on our economy. When we needed more we could get it without making much of a sacrifice. With synfuels, it is necessary to plan ahead, making sure that capital resources are indeed available to supply synfuels projects, and that product demand is also going to be available at least a decade into the future so that large synfuels investments can be amortized.

The current financial situation of many electric utilities in the United States illustrates the risks entailed when plans depend on long-term price and quantity predictions which may prove to be wrong. It was not long ago that utility investments were considered almost risk-free, and the industry had for decades raised all the debt it wished at low rates. Needless to say, the utility situation has now dramatically reversed as the result of sharply rising costs embodied in new, long-lived gener-

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involve many relatively small firms. For example, three of the four major parties in the Great Plains Gasification Project are primarily involved with either gas-distribution or transmission: American Natural Resources Co., Peoples Energy Corp., and Transco Cos. Inc. American Natural Resources is associated with gas-distribution firms operating in Michigan and Wisconsin; Peoples Energy Corp. is associated with Northern Natural Gas, a major distributor in the Midwest; and Transco is the parent company of Transcontinental Gas Pipeline Co., a major operator of transmission lines. The fourth partner, Tenneco, is also a major transmission company, but it was included in the group of top 26 firms listed above because of its chemical processing business. Undoubtedly, all four firms' participation is predicated upon the existence of Government subsidies and loan guarantees, but that is especially true for the three smaller firms.

[20] Comparison based on data for total costs of oil and gas wells, plus estimated costs for predrilling activities over the period from 1959-80. Capital outlays per barrel oil equivalent of reserves over the past 20 years averaged about $1.60. Depending on the synfuels option, a synfuels plant would have a comparable ratio of $5.40 to $7.00/BOE of "reserves." Well-drilling and other exploration costs were obtained from Society of Exploration Geophysicists, Annual Reports and from Joint Association Survey of the U.S. Oil and Gas Producing Industry.

[21] See *1980 Annual Report of Exxon Corporation*, pp. 34, 44, 51.

ating capacity. While it may be premature to draw an analogy with synfuels, it is clear that synfuels will tie up capital in considerably larger blocks and for considerably longer periods than was true for conventional oil and gas reserves over the last 30 years.

Compared with synthetic petroleum, methanol presents two opportunities to partially offset the tendency toward industrial concentration. First, as indicated above, its present use as a major chemical feedstock provides an opportunity for large chemical firms to enter the liquid fuel business. Second, since methanol can be produced from wood and other solid biomass, small-scale conversion plants (approximately $10-million investments) operated by relatively small entrepreneurs may be able to take advantage of local conditions across the country.* Assuming cost competitiveness, having a mixture of small- and large-scale methanol producers may reinforce the attractiveness of downstream equipment investments (e.g., retail pumps and engine improvements), thus making it more likely that drivers will indeed have an attractive methanol option.

Besides methanol, synthetic gases may attract additional large and small firms from outside the petroleum and chemical industries. Depending on the deregulated "wellhead" price of natural gas (relative to fuel liquids) and depending on regulatory policy regarding utility pricing, synthetic natural gas and synthetic medium-Btu gas may become profitable investments for gas utilities. Indeed, the first synthetic gas project to reach the final planning stage has substantial gas utility ownership.** Syngas may become attractive as a methanol coproduct or as a primary product, in either case taking advantage of capital savings and higher conversion efficiencies than if methanol or gasoline is the sole product of indirect liquefaction.

A final comment can be made about the location of the synfuels industry. Shale oil production will be concentrated in Colorado and Utah, since that is where superior shale resources exist and since unprocessed shale cannot be shipped as a crushed rock without driving up costs prohibitively. Coal-based synfuels offer the possibility of spreading liquid fuel production over a wider cross section of the Nation. This is especially important for the Northeast and North Central section of the United States, where there remain substantial coal deposits in Pennsylvania, Ohio, and Illinois, States which have by this time depleted most of their original petroleum reserves.

Unlike their shale counterparts, coal-conversion facilities and subsequent upgrading and refining plants need not be immediately adjacent to the mine mouth, since coal's shipping costs per Btu are less than for shale. Location of facilities and, hence, their regional impacts will depend on site-specific factors and the available modes of transportation. Location of facilities to convert biomass into methanol will be determined primarily by local availability and cost of biomass feedstocks. This restriction is imposed by the dispersed location of plant material, rather than by differences in energy density (biomass feedstocks such as wood have an energy density only marginally lower than some Western coals).

Potential Resource Bottlenecks and Inflation

Technology, ownership concentration, and (in certain important cases) regional concentration, all combine to impose heavy demands on labor, material, and financial resources relative to current and potential new supplies of the same resources. If deployment plans fail to account for supply limitations, long project delays and large cost overruns can occur.

Anytime a capital-intensive industry attempts to start up quickly, temporary factor input shortages can be expected—if not more extreme "bottlenecks" or chronic shortages which generally disrupt construction schedules. Ideally, shortages and, certainly, bottlenecks can be avoided by advanced planning and giving suppliers purchase contracts years in advance if necessary to ensure availability. However, while such planning and long-term commitments minimize shortage risks, they also increase risks of loss should plans be technically ill-conceived and commitments are made to projects with actual costs much larger than planned. These two sets of risks must be weighed against each other, but at the present time technical risks clearly are more significant.

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*One domestic company, International Harvester, is presently developing technology to mass-produce this equipment and transport it to the purchaser's location in easily assembled modules.

**This compares with total private domestic investment in 1980 of about $395 billion, and out of that total about $294 billion went for nonfarm investments in new plant and equipment. Also in 1980, two large blocs of energy investments were $34 billion for oil and gas exploration and production and $35 billion for gas and electric utilities.

In order to predict resource bottlenecks and their impacts, the full array of supplier market dynamics must be understood. In this limited discussion, one can only begin to compare potential demands and supplies for key synfuels resources.

As a final introductory remark, it should be clear that factor price inflation drives up costs in many industries, not just for builders of synfuels plants. Industries that appear most vulnerable to inflation resulting from synfuels deployment will be identified. However, in general, a much larger study would be necessary to trace inflationary pressures through complex interindustry transactions.

Experienced Project Planners, Engineers, and Managers

As planned, the construction of oil shale and coal liquids projects requires the mobilization of thousands of skilled workers and massive quantities of equipment and materials. Of all these synfuels investment resources, the supplies of skilled engineers and project managers are the most difficult to measure, and in the final analysis, it is left up to the large investing firms to decide for each project when a critical mass of talent has been assembled. While individual firms may have excellent engineering departments, the possibility of supply bottlenecks for chemical engineering services, across the full spectrum of chemical processing industries, must be of concern because of the potential financial risks due to design errors and because of the length of time required to educate and train new people.*

At the present time, only one of the country's 10 major architectural and engineering (A&E) firms[22] has actually built a synfuels plant.* No commercial-scale plant has been built. Given this general inexperience, and making the reasonable assumption that A&E firms will not be short of work worldwide, it seems highly unlikely that synfuels construction contracts for the first round of a rapid deployment scheme will be able to hold builders to binding cost targets and completion dates. Consequently, those who would actually take investment risks may be extremely skeptical of builders' qualifications and judgment, and this may severely limit the apparent supply of qualified engineers and engineering firms.

Furthermore, if synfuels projects proceed ahead at a rapid pace despite the technical uncertainties and commercial inexperience, it could drive up the A&E costs for other large, new processing facilities which rely on the same limited group of A&E firms and the same pool of skilled workers. Of all synfuels resource markets, the possibilities for propagation of inflation from synfuels into the rest of the economy is greatest here. Petrochemicals, oil refining, and electric power generation are all industries which depend on the same engineering resources in order to build new facilities. In 1979, these three industries accounted for more than 25 percent of the total investment in new plant and equipment.[23]

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*Well-trained engineers and project planners can still make major mistakes, but risks due to miscalculations and design errors are controlled by careful training and building up experience incrementally. Commonly accepted periods for obtaining a bachelor's degree and subsequent on-the-job training range from 6 to 10 years.

Several recent examples illustrate that errors in the design of large mining and chemical processing plants do occur and can cause severe cost overruns and project delays. Perhaps the most extreme case was the Midwest (nuclear) Fuel Reprocessing Plant built for General Electric. Construction started in 1968, with completion planned for 1970 at an estimated cost of $36 million. Unfortunately, expected time for major technical component failure in the new plant was less than the time required to achieve stable operating conditions. The project was abandoned and the company estimated that an additional expenditure of between $90 million and $130 million would have been required to redesign and rebuild.

Additional examples include a municipal solid waste gasifier in Baltimore begun in 1973 which never achieved its major goal of commercial steam production, an oil sands project in Canada which underwent extensive retrofit when the teeth of its large mining shovels were worn away in a matter of weeks by frozen oil sands, and so on. Clearly, major design errors have happened in the past and are likely in the future, with the number and severity of such errors increasing if a shortage of experienced design engineers develops.

For further information about these and other examples of design errors, see Edward Merrow, Stephen Chapel, and Christopher Worthing, *A Review of Cost Estimation in New Technologies: Implication for Energy Process Plants and Corporations*, July 1979.

[22] According to *Business Week*, Sept. 29, 1980, p. 84, the 10 major A&E firms, in order of their largest projects to date, are: Fluor, Parsons, Bechtel, Foster Wheeler, C-E Lummus, Brown and Root, Pullman Kellog, Stone and Webster, CF Braun, and Badger.

*The Fluor Corp. built Sasol I and II in South Africa and will undoubtedly sell this technology and its unique experience in the United States. However, different resource endowments can cause very different engineering economics in different countries, and thus this existing technical base may have to be adapted to the United States by investing in significant additional engineering.

Mining and Processing Equipment, Including Critical Metals for Steel Alloys

The construction of massive and complex synfuels plants will require equally massive and diverse supplies of processing equipment and construction materials. Some of this equipment must meet high performance standards for engineering, metals fabrication, component casting, and final product assembly because it must withstand corrosive and abrasive materials under high pressure and temperature.

Potential supply problems can be identified first by comparing projected peak annual equipment demand (for each deployment scenario) to current annual domestic production. While projections were not done specifically for OTA's low and high scenarios, useful information can be extrapolated from an earlier projection for the deployment of coal liquids.[24] In that analysis, which postulated 3 million barrels per day (MMB/D) of synfuels by 2000, 7 of 18 input categories were identified as questionable because projected synfuels demands account for a significant fraction of domestic production.* Supply problems for chromium, the one item in this group of seven which is not a manufactured piece of equipment, would not be caused by synfuels deployment, since synfuels requirements would amount to less than 3 percent of domestic consumption, but supplies may nevertheless be difficult to obtain because U.S. supply is imported, much of it from politically unstable southern Africa.[25]

For the six types of equipment identified the actual occurrence of bottlenecks will depend on the ability of domestic industry to expand with synfuels demand. In all cases, including draglines and heat exchangers—where coal synfuels requirements exceed 75 percent of current domestic production even in the low scenario—there appear to be no technical or institutional reasons why, if given notice during the required project planning period, supplies should not expand to meet demand with relatively small price incentives.

In general, this optimistic conclusion is based on the fact that leadtimes for expanding capacity to produce synfuels equipment are shorter than the leadtimes required to definitely plan and then build a synfuels plant.[26] The fact that many plants would be built at the same time does not nullify this basic comparison as long as all synfuels construction projects are visible to supplier industries, as they should be. Furthermore, foreign equipment suppliers can be expected to make up for deficiencies in domestic supply if not actually displace domestic competitors.

For example, consider the case of heat exchangers. As indicated in table 62, coal synfuels

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[23] For data see *Statistical Abstract,* 1980, p. 652.

[24] Data obtained from "A Preliminary Study of Potential Impediments," by Bechtel National, Inc., which is one part of a three-part compendium, *Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990,* TRW, March 1980. We can extrapolate from coal liquids to all other synfuels because subsequent research (by E. J. Bentz & Associates, OTA contractor) indicates that shale oil, coal liquids, and coal gases are all quite similar in their total use of processing equipment per unit output (measured in dollars) and in their mix of processing equipment. Furthermore, the Bechtel study remains useful, despite its age, since subsequent increments in synfuels plant costs do not add items to this list or significantly increase demand requirements for the group of seven critical items. In other words, recent escalations in plant costs are primarily related to increases in the expected prices of components and to increasing demands for certain components which are insignificant when compared with productive capacity nationwide.

*Significance in this case means that projected synfuels demand exceeds 1 to 2 percent of domestic production. Since this is a relatively low threshold, this list should stay about the same for both scenarios.

[25] The chief use of chromium is to form alloys with iron, nickel or cobalt. In the United States, deposits of chromite ore are found on the west coast and in Montana. However, domestic production costs are much higher than in certain key foreign countries. In 1977, South Africa produced about 34 percent of total world production, with the U.S.S.R. and Albania producing another 34 percent. Other major producers are Turkey, the Phillipines, and Zimbabwe. See *Minerals in the U.S. Economy: Ten-Year Supply-Demand Profiles for Nonfuel Mineral Commodities* (1968-77), Bureau of Mines, U.S. Department of Interior, 1979.

[26] One can never be certain about how well industrial systems will adapt to rapidly expanding demand for a limited number of highly engineered types of equipment which must be produced with stringent quality control. However, informal surveys of equipment manufacturers have not revealed substantial reasons why equipment supplies should not be responsive to moderate price incentives. See Frost and Sullivan, *Coal Liquefaction and Gasification: Plant and Equipment Markets 1980-2000,* August 1979.

Table 62.—Potentially Critical Materials and Equipment for Coal Liquids Development

Category	Units	(A) Peak annual requirements	(B) U.S. production capacity	(A)/(B) (percent)
1. Chromium	tons	10,400	0	—
2. Valves, alloys, and stainless	tons	5,900	70,000	8
3. Draglines	yd	2,200	2,500	88
4. Pumps and drivers (less than 1,000 hp)	hp	830,000	20,000,000	4
5. Centrifugal compressors (less than 10,000 hp	hp	1,990,000	11,000,000	18
6. Heat exchangers	ft²	36,800,000	50,000,000	74
7. Pressure vessels (1.5 to 4 inch walls)	tons	82,500	671,000	12
8. Pressure vessels (greater than 4 inch walls)	tons	30,800	240,000	13

SOURCE: *Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990*, draft prepared for the Department of Energy by TRW, Inc. and Bechtel National, Inc., March 1980, pp. 4-28. Although these projections apply to the achievement of 3 MMB/D of coal liquids, and not specifically to the low and high production scenarios postulated in this report, they nevertheless indicate rough orders of magnitude for equipment demand. See footnote 16 of this chapter for further discussion of alternative synfuels projections.

requirements for the low scenario could account for about 75 percent of current domestic U.S. production. Extrapolation from table 62 indicates that requirements for the high scenario could amount to 150 percent of current production and, as data in table 63 indicate, even in the low scenario, synfuels demand could exceed current U.S. production for "fin type" heat exchangers. However, productive capacity can expand as rapidly as machine operators and welders can be trained, which for an individual worker is measured in terms of weeks and months. Additional heat-treated steel and aluminum inputs will also be required, as well as manufacturing equipment, but in all cases supplies of these inputs should expand with demand.[27]

This generally optimistic assessment does not mean that temporary shortages could not occur and temporarily drive up equipment prices if prospects for synfuels deployment should improve dramatically.[28] However, as orders for new equipment skyrocket, new capacity should become available in time so that extremely high equipment prices can be avoided if project managers are willing to accept relatively brief (measured in months) delays in delivery.

Skilled Mining and Construction Labor

Construction workers and their families can move with employment opportunities, but moving is costly and especially burdensome if jobs in an area last for only a period of months. In order to induce essential migration, synfuels projects must incur high labor costs in the form of travel and subsistence payments as well as

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[27] Compared with the full range of heat exchangers used in industrial and utility applications, those likely to be used in synfuels plants will operate at relatively low temperatures. Low-temperature units are made primarily out of carbon steel, low-alloy steel, and enamel steel, all of which are readily available in commodity markets where demand for heat exchangers is a small fraction of the total. Hence, material inputs are unlikely to restrain expansion of heat exchanger supplies.

It is also unlikely that skilled labor or manufacturing plant and equipment will limit supplies, because the required welding and machine operator skills can be learned in a period of weeks if necessary, and manufacturing facilities are not highly specialized. Background information about the heat exchanger industry, and synfuels technology in particular, was obtained by private communication with James Cronin, Manager of Projects, Air Preheater Division, Combustion Engineering, Wellsville, N.Y.

[28] A commonly cited example of a temporary inflationary spurt, caused by a construction boom, occurred in the U.S. petrochemicals industry in 1973-75. Over the period from the mid-1960's to mid-1970's, the following three price indices show a distinctive pattern for chemical process equipment:

Year	Chemical process equipment[a]	Producer goods[b]	All machinery and Equipment[b]
1967	100	100	100
1970	81	110	111
1971	86	119	118
1972	74	135	122
1973	91	160	139
1974	139	175	161
1975	167	183	171
1976	188	194	182
1977	154	209	206

[a] Data obtained from Annual Survey of Manufacturers, Bureau of Census, U.S. Department of Commerce, SIC No. 35591 005, as reported in ASM-2.

[b] Data obtained from U.S. Statistical Abstract, 1979, pp. 477-79.

In words, chemical process equipment prices reversed a decline in 1973, increased by more than 150 percent through 1976, and then tapered off again in 1977. This compares with a steady upward trend from both producer goods and all machinery and equipment.

Table 63.—Peak Requirements and Present Manufacturing Capacity for Heat Exchangers (Million Square Feet)

	Peak requirements for 3 MMB/D of coal liquids (1985)[a]	U.S. manufacturing capacity
1. Process shells and tubes	22.0	27
2. Fin type	9.2	8
3. Condensers	4.4	15
	36.8	50

[a] Peak requirements indicate maximum capacity requirements if synfuels projects are to maintain production schedules.

SOURCE: *Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990*, draft prepared for the Department of Energy by TRW, Inc. and Bechtel National, Inc., March 1980, pp. 4-28.

"scheduled overtime."* However, while the influx of people and the relatively high payments to workers may cause severe local inflation, regional and national impacts should not be significant. Confidence in this conclusion is based primarily on the fact that training in construction skills can be obtained in the period of weeks and months and that, if anything, there is an oversupply of people willing to enter these trades.[29]

Miners will be expected to move into a new area and stay permanently. Although it would seem reasonable to suppose that workers would be reluctant to mine underground, where working conditions can be unpleasant and hazardous, historical experience suggests otherwise. In the Eastern mines, with present wages about 140 percent of the national average in manufacturing, labor shortages have not been a serious problem.[30]

Basic Construction Materials

Among all synfuels resources, basic construction materials (primarily steel and concrete) are least likely to cause serious bottlenecks. The more rapid the pace of deployment, the more likely a premium price must be paid for steel and cement, but supplies of both should be highly responsive to price incentives.

Mineral resources for the manufacture of Portland cement (the class of hydrolic cement used for construction) are widely distributed across all regions of the Nation. The same is true for the sand and gravel that are mixed with cement and water to make concrete. The only constraint on supplies of cement or concrete is the time required to construct new capacity, which takes at most 3 years for a new cement plant and much less than that for a concrete mixing facility.[31] Since these times are short relative to the construction period for a synfuels project, cement shortages should not be a serious problem.

Steel supplies, on the other hand, may be insufficient in certain regions because required resources such as iron ore, scrap, and coking coal are not widely distributed. However, steel can be shipped long distances without dramatically raising costs. For example, unfabricated structural shapes and plates (e.g., I beams) are valued today at approximately $25 per hundred pounds FOB

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*Apparently, it is important for major employers to emphasize that they do not pay premium wages and salaries for large construction projects, but instead there are various special considerations. Whatever it is called, total worker remuneration appears to provide an abnormally large incentive.

[29] Bechtel's experience at nuclear powerplant sites in Michigan, Pennsylvania, and Arizona has demonstrated that a person with limited welding experience can be upgraded to "nuclear quality" in 6 to 12 weeks of intensive training. See Bechtel, "Production of Synthetic Liquids," pp. 4-23. Actual training periods are influenced by various institutional factors. For further discussion of labor productivity see K. C. Kusterer, *Labor Productivity in Heavy Construction: Impact on Synfuels Program Employment*, Argonne National Laboratory, ANL/AA-24, U.S. Department of Energy.

The supply of people willing to work on large construction projects seems to be very price-elastic. In other words, large numbers of skilled or "able-and-willing-to-learn" workers will migrate to even remote construction sites if wage incentives exceed going rates elsewhere in the Nation by 20-30 percent. Although it is difficult to confirm this conclusion in published literature, it appears to be commonly held among university-based experts as well as in the construction industry. Information was obtained from private communications with J. D. Borcherding, Department of Civil Engineering, University of Texas in Austin; Richard Larew, Department of Civil Engineering, Ohio State University; John Racz, Synfuels Project Manager, Exxon USA in Houston; and Dan Mundy, Building Construction Trades Department, AFL-CIO, in Washington, D.C.

[30] As prescribed in the new United Mine Workers/Bituminous Operators Association contract, dated June 6, 1981, underground miners presently earn $10 to $11.76 per hour and surface miners $11.15 to $12.53. This compares with the national average wage in manufacturing of $7.80 and the average wage in construction of $9.90, both calculated for March 1981. See *Monthly Labor Review*, May 1981, p. 84, for additional wage data. The generalization, that labor supply has not been a serious problem, is a conclusion reached but stated only implicitly in an OTA report, *The Direct Use of Coal*, op. cit.

[31] Information about the resource base and construction leadtimes obtained by private communication with Richard Whitaker, Director of Marketing and Economic Research, Portland Cement Association, Skokie, Ill.

(freight on board at the factory) and they are commonly shipped from Bethlehem, Pa., to Salt Lake City, Utah, for another $4 per hundred pounds. In other words, even if local production is insufficient to meet the needs of synfuels deployment, vast additional supplies from a national network of suppliers can be shipped into the area without driving up costs excessively.[32]

Final Comments

Despite OTA's conclusions that resource shortages other than engineering skills need not obstruct synfuels deployment, it does not follow that rapid synfuels deployment would not be inflationary for a broad range of resource inputs. Disregarding the prospect of Federal intervention to speed up deployment or to alleviate impacts, rapid deployment could cause bursts of inflation in an economy where certain suppliers have dominant market positions at least within regions, where skilled workers are reasonably well organized, and where people have grown accustomed to inflation. In such circumstances, it would be surprising if those with power to negotiate their revenues and incomes did not exercise it to their advantage when demand for their product and services is rapidly expanding.

Another caveat should also be made concerning the importation of processing equipment. If foreign suppliers compete successfully and become major suppliers of synfuels equipment, as they have already demonstrated in the Great Plains Gasification Project, rapid deployment could result in substantial foreign payments.[33] Depending on the general balance of payments picture, this could devalue the dollar in foreign exchange markets and thus increase the price of all imports into the United States. Perhaps offsetting this concern about balance of payments, the success of equipment imports may have a salutary effect on domestic producers by inducing them to improve their products and lower their costs.

Finance Capital and Inflation

In addition to potential shortages among resource inputs, the deployment of synfuels capacity may be restrained by the limited availability of financial capital. Such a limit has already been mentioned for small companies which cannot raise $2 billion to $3 billion and for any company trying to borrow at presently inflated interest rates.

Limits may also be imposed by financial markets that compare synfuels against all other types of investments. If synfuels projects are indeed unprofitable, the number of projects funded may be small or, if they are profitable, the number may be large. In this sense, a market-based synfuels deployment scenario should be self-correcting, with the lure of profits attracting new investment when expansion is warranted and the pain of losses driving investors away and thus curtailing deployment. Any of the previously discussed shortage possibilities, should they arise, will be perceived sooner or later by investors and the number of projects reduced as a result.

Whether or not deployment is by market incentives or Government policy, the adjustment and possible disruption of financial markets required by synfuels deployment can be discussed in terms of gross investment data. Assume that on the average, during its 5-year construction period, a $2.5-billion synfuels project requires $500 million in outlays annually. This compares with total private domestic investment in 1980 of about $395 billion, of which total about $294 billion went for nonfarm investments in new plant and equipment. Also in 1980, two large blocs of energy investments were $34 bilion for oil and gas exploration and production and $35 billion for gas and electric utilities.[34]

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[32] Data obtained from *American Metal Market*, June 16, 1981, and from Bethlehem Steel, Washington Office. It should be noted that fabricated steel or steel which has been tailored to specific applications can cost as much as $75 per hundred pounds and hence shipping costs may add much less to delivered costs (on a percentage basis).

[33] In this first major synfuels project, the Japanese low bid was substantially below apparent costs. Among other things, this indicates the competitive determination of at least one foreign supplier to capitalize on synfuels deployment. For related comments by U.S. Steel firms, see *Metals Daily*, Sept. 4, 1980; and the Chicago Tribune, Aug. 30, 1980. For a general analysis of the U.S. steel industry and its competition from abroad, see *Technology and Steel Industry Competitiveness;* OTA-M-122 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1980).

[34] All investment data except for oil and gas were obtained from the *Survey of Current Business*, Bureau of Economic Analysis, U.S. Department of Commerce, September 1981, pp. 9, S1. Oil and gas

In other words, 12 fossil synfuels plants under construction at the same time would account for about 18 percent of the 1980 investments for the production of petroleum and natural gas, about 17 percent of 1980 investments by electric utilities, or about 5 percent of the total investment in manufacturing. At this pace, assuming 5-year construction periods, approximately 2 MMB/D capacity could be installed over the next 20 years (the low scenario). Almost three times this many plants on the average must be under construction at one time, and about three times as much capital must be committed to achieve the goal of just under 6 MMB/D by 2000 (high scenario). In either case, this average would be achieved by means of a relatively gradual startup, as technologies are proven and experience is gained in construction, followed by a rapid buildup as all systems become routine.

The question remains: Can funding be reasonably expected for scenarios presented in this report? The answer depends on the future growth of GNP and the future value of liquid fuels relative to other fuels and to all other commodities. Without trying to predict the future, the question may be partially answered by showing that such a diversion of funds to energy applications has precedents in recent history.

From 1970 to 1978, investments in oil and gas grew at a rate of about 7.5 percent per year and investments in electric utilities grew at about 5 percent per year, both in constant dollars.[35] A glance back at synfuels requirements as fractions of existing energy investments shows that it would take only about 2.5 years of 7.5 percent growth in oil and gas investments or about 3.5 years of 5 percent growth in electric utility investments to provide sufficient incremental funds to support the low scenario, and about three times as many years of growth in each case to fund the high scenario.

In other words, another 5-year period of expansion in energy investments, similar to their growth in 1970-78 with oil and gas and electricity added together, could provide more than enough funds annually to reach the goal of about 6 MMB/D of synfuels by 2000 (high scenario), assuming that this higher level of investment were sustained for the next 20 years. Furthermore, if such rapid deployment were economically justified (i.e., other costs were rising sufficiently to make synfuels relatively low-cost options) there would be an economic incentive to divert funds to synfuels which had been devoted to conventional fuels.

Final Comments About Inflation and Synfuels

In an inflating economy, all price increments tend to be viewed as inflationary. However, this appearance obscures the fact that some price increases are necessary adjustments in relative prices in order to reduce consumption and to increase production. The latter will be true if synfuels place large, long-term, new demands on scarce human and material resources.

On the other hand, construction costs have grown faster than the general rate of inflation since the mid-1960's.[36] (See fig. 19.) Recently, the reverse has been true but there is reason to be concerned that rapid synfuels deployment could exacerbate what has been a serious inflationary problem. In any case, rising real costs of construction has been one of the major reasons why "current" estimates of synfuels costs have more or less kept pace with rising oil prices. (See ch. 6 for more detailed discussion.)

Finally, although most of this discussion has explored how synfuels deployment may aggravate inflation, the cause and effect could be reversed if deployment of first generation plants is too slow. That is, if the promise of synfuels remains

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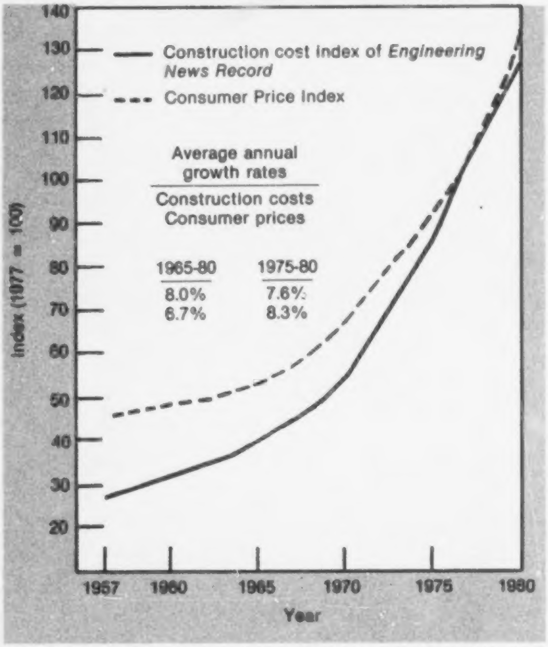
investment data were obtained from *Petroleum Industry Investments in the 80's,* Chase Manhatten Bank, October 1981. The total of $34 billion is broken down into $22 billion for service equipment, $6.3 billion for lease bonuses, and $3.1 billion for geological and geophysical data gathering.

[35] Energy investment growth data obtained from *1978 Annual Report to Congress,* Energy Information Administration, p. 128.

[36] Consumer Price Index obtained from *1980 U.S. Statistical Abstract,* p. 476. Construction Cost Index obtained from *Engineering News Record,* McGraw Hill, Dec. 4, 1981, Market Trends Section. The actual data series published in this journal has been converted from a base year of 1916 to a base year of 1977. There are several construction cost indices published by reputable sources, but only the ENR was reproduced here because the data available to OTA suggest that all such series reflect more or less the same trends.

Figure 19.—Time Series Comparison: Construction Costs and Consumer Prices



SOURCE: U.S. Bureau of Labor Statistics, "Monthly Labor Review and Handbook of Labor Statistics," annual, and "BM and ID Investment Manual," *Investment Engineering*, sec. I, part 6, item 614, pg. 1, Apr. 16, 1981.

in the distant future and conservation attempts are clearly insufficient to balance oil supply and demand worldwide, there will be no market-imposed lid on the price of oil and no reason to expect that sharp oil import price increases will not continue to destabilize domestic prices. In that case, the inflationary impacts of rapid deployment may appear to be much more acceptable.

Chapter 9

Social Effects and Impacts

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Chapter 9

Social Effects and Impacts

INTRODUCTION

Increased automotive fuel efficiency and production of synthetic fuels will both give rise to a variety of social impacts. The impacts of increasing fuel efficiency will occur primarily as changes in employment conditions, while the impacts of producing synthetic fuels will be felt primarily in communities which experience rapid surges and declines in population as plants are built and begin to operate.

SOCIAL IMPACTS OF CHANGING AUTOMOTIVE TECHNOLOGY

Overview

The characteristics and uses of automobiles sold in the United States indicate that historically Americans have valued automobiles not only for personal transportation but also as objects of style, comfort, convenience, and power. Substantial increases in the costs of owning and operating automobiles that occurred during the 1970's, and that are expected in the future, are motivating consumers to change their attitudes and behavior in order to reduce spending on personal transportation. Some have purchased smaller, more fuel-efficient vehicles. Others have chosen to keep their present vehicles longer. Large numbers are simply driving less. Since January 1979, the combined subcompact and compact share of total sales has climbed from 44 to 61 percent, and gasoline consumption has declined 12 percent. About one-half to three-quarters of these fuel savings can be attributed to increased fuel efficiency of the automobile fleet.

Although about 12 percent of personal consumption expenditures has historically gone to automobile ownership and operation, rising costs may ultimately induce consumers to spend a smaller share of their budgets on automobiles or —at least—not to let that share increase. Recent increases in the small-car proportion of new-car sales suggest that consumers are prepared to trade cargo space and towing capability for high fuel economy and the prospect of relatively low operating costs. In the future, instead of buying vehicles designed for their most demanding transportation needs, people may buy small vehicles for daily use and rent larger vehicles for infrequent trips with several passengers, bulky or heavy cargo, or towing. The movement toward small cars is slowed by the tendency for people to retain cars longer than before.* Purchases of fuel-efficient vehicles and ownership of several vehicles, each suited for different transportation needs, would be facilitated by improved economic conditions.

Ridesharing and mass transit use have become more common and could increase further. Since the 1973-74 oil embargo public transit ridership has increased 25 percent.[1] Ridesharing and transit use are limited by the dispersion of residences and jobs, and, for transit, by the adequacy and availability of facilities. Mass transit capacity is limited during peak commuting periods and often is unavailable or scheduled infrequently in areas outside of central cities.

It should be noted that low-income people are likely to have the fewest options for adjusting to rising automobile costs. People with low incomes already tend to own fewer vehicles, have relatively old vehicles (which were typically bought used), travel less, and share rides or use public transit more than the affluent.

Consumers are likely to respond differently to electric vehicles (EVs) and small conventionally powered cars (using internal combustion engines) because of different cost, range, and refueling attributes (see table 64). The conventionally powered car would have two significant advantages over an EV: unlimited range (with refueling) and substantially lower first cost. The EV, on the other hand, would offer the advantage of being powered by a secure source of energy (electricity) and therefore assure mobility in the event of disruption of gasoline supplies. It is not clear how the consumer would weigh these two options, although the degree to which EV manufacturers can reduce the cost differential is certain to be very important.

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*Thirty-five percent of private vehicles were over 5 years old in 1969, 51 percent were over 5 years old in 1978.

[1] American Public Transit Association.

Employment

In 1980, the Bureau of Labor Statistics estimated that there were fewer than 800,000 people employed in primary automobile manufacturing and automotive parts and accessories manufacturing. This compares with employment levels over 900,000 during the peak automobile production period, 1978-79.[2] These figures, however, present an incomplete picture of employment. Although the Bureau of the Census counts employees in industries producing various primary products, it does not identify how many workers contribute to intermediate products used in automobiles or other finished goods. Thousands of automotive people perform work in support of automobile manufacturing within industries otherwise classified—producing, for example, glass vehicular lighting, ignition systems, storage batteries, and valves. Thus, the Department of Transportation estimated that during 1978 to 1979 about 1.4 million people were employed by auto suppliers overall.[3]

Historically, the growing but cyclical nature of the auto market resulted in a pattern of periodic growth and decline in auto-related employment (see table 65). Current and projected trends for strong import sales, decline in the growth rate of the U.S. auto market, increased use of foreign suppliers and production facilities, and adoption of more capital-intensive production processes and more efficient management by auto manufacturers and suppliers will contribute to a general decline in auto industry employment.

Specific changes in employment will depend on the number of plants closed or operating un-

Table 64.—Initial and Lifecycle Costs of Representative Four-Passenger Electric Cars

	Near term					Advanced		
	Pb-Acid	Ni-Fe	Ni-Zn	Zn-CL$_2$	(ICE)	Zn-CL$_2$	Li-MS	(ICE)
Initial cost, dollars	8,520	8,400	8,130	8,120	4,740	7,050	6,810	5,140
Vehicle	6,660	5,950	5,720	5,540	4,740	5,410	5,180	5,140
Battery	1,860	2,450	2,410	2,580	—	1,640	1,630	—
Lifecycle cost, cents per mile	23.9	24.9	26.6	22.0	21.4	19.4	20.1	21.8
Vehicle	5.0	4.5	4.3	4.2	4.3	4.1	3.9	4.7
Battery	3.0	4.8	7.0	2.3	—	1.4	2.6	—
Repairs and maintenance	1.5	1.5	1.5	1.5	3.9	1.5	1.5	3.9
Replacement tires	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
Insurance	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Garaging, parking, tolls, etc.	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Title, license, registration, etc.	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Electricity	2.3	2.2	2.0	2.2	—	1.7	1.5	—
Fuel and oil	—	—	—	—	4.0	—	—	3.7
Cost of capital	5.5	5.5	5.4	5.4	3.0	4.5	4.4	3.3

NOTE: All costs are in mid-1980 dollars.

Assumptions:

Electricity price	$0.03 per kilowatt-hour
Gasoline price	$1.25 per gallon
Electric vehicle life	12 years
Internal combustion engines vehicle life	10 years
Annual travel	10,000 miles
Car and battery salvage value	10 percent
Cost of capital	10 percent per year

Car and battery purchases are 100 percent financed over their useful lives.

Electricity cost includes a road use tax equal to that paid by typical gasoline vehicles of equal weight via State and Federal gasoline taxes.

SOURCE: General Research Corp. Cost categories and many entries, such as tires, insurance, garaging, etc., are based on periodic cost analyses by the Department of Transportation (see footnote 13). All costs shown were computed by the Electric Vehicle Weight and Cost Model (EVWAC) (see footnote 14).

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[2] Bureau of Labor Statistics, Current Employment Statistics Program data.

[3] U.S. Department of Transportation, *The U.S. Automobile Industry, 1980: Report to the President from the Secretary of Transportation* (Washington, D.C: Department of Transportation, January 1981).

Table 65.—Auto Industry Employment Data

Year	(1) Average annual unemployment rate in the motor vehicle industry SIC 371 (percent)	(2) Average annual employment in primary auto manufacturing and parts and accessories manufacturing, SIC 3711 and SIC 3714 (000)
1970. . . .	7.0	733.4
1971. . . .	5.1	781.3
1972. . . .	4.4	798.2
1973. . . .	2.4	891.5
1974. . . .	9.3	818.9
1975. . . .	16.0	727.8
1976. . . .	6.0	814.9
1977. . . .	3.9	869.5
1978. . . .	4.1	921.7
1979. . . .	7.4	908.6
1980. . . .	20.3	775.6

SOURCE: Column 1 data are from the Bureau of Labor Statistics, household sample survey. Column 2 data are from the Bureau of Labor Statistics establishment survey. Data in the two columns are not directly comparable. "SIC" refers to "Standard Industrial Classification."

der capacity, the capacity of the plants, and the degree to which production at affected plants is labor-intensive. The long-term effects on workers depend on personal characteristics such as skills (many production workers have few transferable skills), the levels of local and national unemployment, information about job opportunities, and personal mobility (greatest for the young, the skilled, and those with some money).

The Department of Transportation estimates that each unemployed autoworker costs Federal and State Governments almost $15,000 per year in transfer payments and lost tax revenues. This estimate implies, for example, that if 100,000 to 500,000 manufacturer and supplier workers are unemployed for a year their cost to government is about $1.5 billion to $7.5 billion. During 1980, payments to unemployed workers of General Motors (GM), Ford, and Chrysler in Michigan included about $380 million in unemployment insurance, $100 million in extended benefits, and $800 million in "trade adjustment assistance" (provided by a program established in the Trade Expansion Act of 1962 and modified by the Trade Act of 1974).[4]

Growing use of labor-saving machinery by auto manufacturers and major suppliers to implement complex technologies, cut costs, and improve product quality is reducing job opportunities in the auto industry. GM, for example, expects to invest almost $1 billion by 1990 for 13,000 new robots for automobile assembly and painting and parts handling. A new robotic clamping and welding system developed by GM and Robogate Systems, Inc., will enable GM to reduce labor costs for welding by about 70 percent, improve welding consistency, and reduce vibration and rattling in finished automobiles.[5]

MacLennan and O'Donnell, analysts at DOT, have calculated that today's new and refurbished plants can assemble 70 cars/hour with an average employment level of 4,500, while older plants typically produce 45 to 60 cars/hour using about 5,400 workers. Such plant modernization implies that three fewer assembly plants and 23,000 fewer workers are needed to assemble 2 million cars annually.[6] The United Auto Workers estimates that labor requirements in auto assembly, which has been a relatively labor-intensive aspect of auto manufacture, will be reduced by up to 50 percent by 1990 through the use of robots and other forms of automation.[7]

Foreign-designed automobiles manufactured in the United States also provide jobs. Current and anticipated local production by foreign firms (only Volkswagen (VW) to date) largely involves vehicle assembly, using primarily imported components and parts. VW's Pennsylvania plant employs 7,500 workers to assemble over 200,000 cars and contributes to about 15,000 domestic supplier jobs;[8] a comparably sized domestic-owned plant would support a total of about 35,000 domestic jobs. New U.S. manufacturing and supplier jobs will grow with local production and purchasing from U.S. suppliers by foreign firms in proportion to the amount of local production content in the automobiles. The planned increase in local content for Rabbits made here by VW—from 70 percent in model

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[4] Michigan Employment Security Commission, personal communication.

[5] "GM's Ambitious Plans to Employ Robots," *Business Week*, Mar. 16, 1981.

[6] Carol MacLennan and John O'Donnell, "The Effects of the Automotive Transition on Employment: A Plant and Community Study" (Washington, D.C: U.S. Department of Transportation, December 1980).

[7] *Business Week*, op. cit.

[8] Department of Transportation, op. cit.

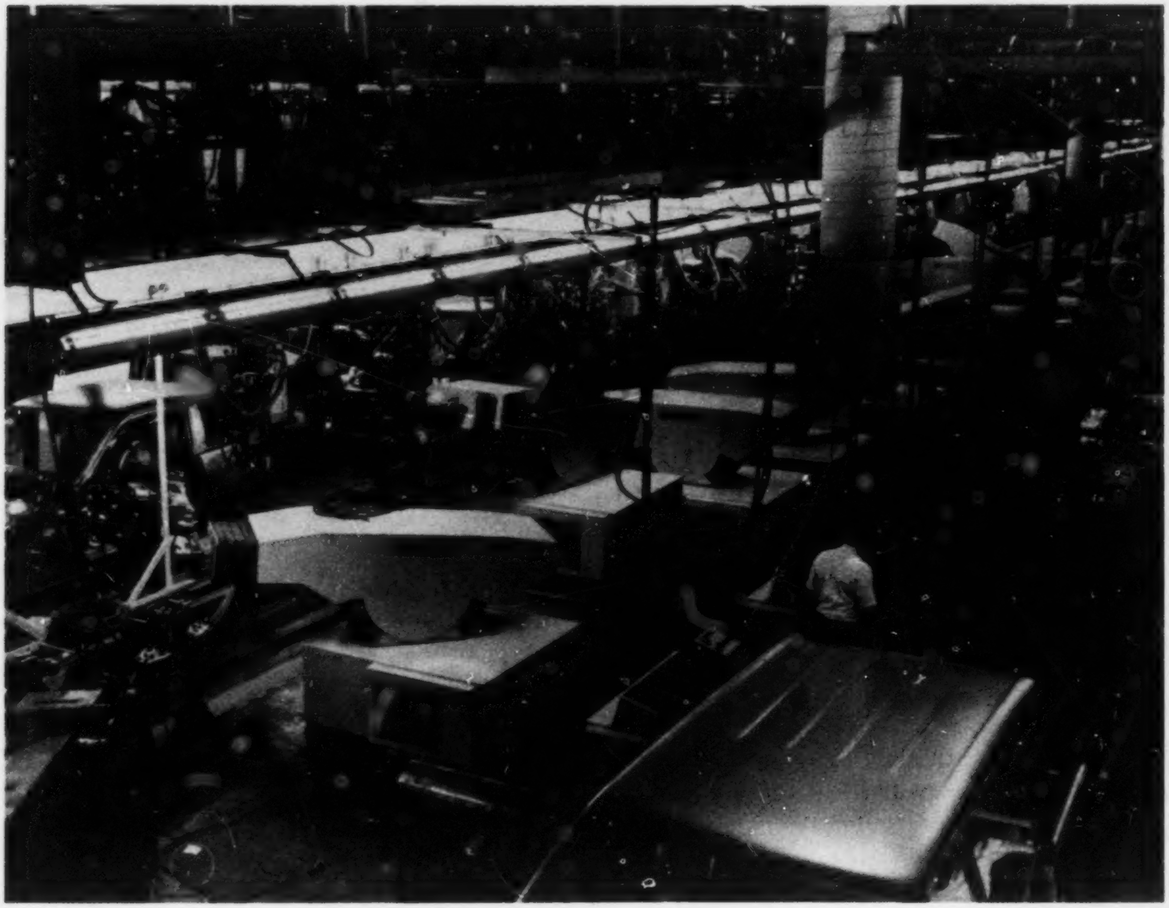

Photo credit: General Motors Co.

Automated welders illustrate the changing nature of the auto manufacturing workplace

year 1981 to 74 percent in model year 1983—implies more work in the United States.[9]

The Departments of Labor and Transportation estimate that there are between one and two supplier jobs overall for each primary auto manufacturing job.[10] Change in supplier employment associated with declining manufacturing employment is uncertain, and will depend on the nature of the supplied product, how it is made, and the amount that auto manufacturers buy. While some supplier jobs, like auto manufacturing jobs, depend on production volume, other supplier jobs (e.g., in machine tool manufacture and plastics processing) are tied to the implementation of new technology. Trends toward foreign sourcing and vehicle production and automation among suppliers suggest that supplier employment overall will decline.

Steel and rubber industry jobs are especially vulnerable to automotive weight and volume reductions. Many of these supplier jobs have already been lost with automotive weight reductions during the 1970's. For example, MacLennan and O'Donnell estimate that reduced automotive use of iron and steel in 1975 to 1980 led to a permanent loss of 20,000 jobs, a loss only partially offset by a gain of 8,000 jobs in processing plastics and aluminum for automotive use.[11] During the same period, employment in the tire and rubber industry declined at a compound annual rate of 4.1 percent.[12]

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[9] "VW Projects Increases in U.S. Content," *Ward's Automotive Reports*, May 27, 1981.

[10] MacLennan and O'Donnell, op. cit.

Jobs with parts and component manufacturers are also relatively vulnerable, although, again, many have already been lost. MacLennan and O'Donnell estimate that the closing of almost 100 materials, parts, and component plants in 1979 to 1980 eliminated over 80,000 supplier jobs.[13] Because of the predominance of small firms among auto suppliers, near-term supplier job losses may occur incrementally.

Automobile importation supports some domestic jobs and results in the loss of others. There are over 125,000 people employed by importers, primarily in dealerships.[14] Growth in import-related employment stems from increases in the number and market shares of importers, in the number of dealerships per importer, and in employment per dealership. On the other hand, imports cause loss of industrial jobs. DOT estimates that loss of 100,000 vehicle sales to imports results in the loss of about 8,500 primary manufacturing and 13,000 to 16,000 supplier jobs.[15] This implies, for example, that the almost 400,000-unit increase in import sales in 1978 to 1980 caused a loss of 34,000 jobs in automobile manufacturing and up to 64,000 supplier jobs.

Employment in automotive services, including repair, parking, renting and leasing, washing, and other services (Standard Industrial Classification 75) grew at a compound annual rate of 5.7 percent in 1975 to 1980 to a total level of almost 540,000 people, according to the Department of Commerce.[16] Employment in these areas is expected to continue to grow.

Occupational and Regional Issues

Improvements in automotive technology cause changes in the skills required for production jobs. Major design and technology changes increase demands for engineers, who have been in short supply, while cost-cutting strategies eliminate other white-collar positions. GM, for example, eliminated about 10,000 white-collar jobs beginning in 1980 to save about $300 million, and may eliminate up to 20,000 more.[17] Automation reduces the number of routine and hazardous tasks, while increasing equipment maintenance and service tasks. GM, for example, plans to have equal numbers of skilled and unskilled workers by the 1990's, although it presently has one skilled worker for each five to six unskilled workers.[18]

Auto production jobs are concentrated in Michigan, Ohio, Indiana, New York, and Illinois (see fig. 20). The geographic distribution of auto-related jobs is likely to change somewhat for several reasons. First, some nontraditional auto suppliers are located away from traditional areas of auto production. Major plastics-producing States, for example, include California, New Jersey, and Texas as well as Ohio and Illinois. Furthermore, many of today's suppliers are located abroad and many U.S. suppliers are opening plants abroad. Second, foreign or domestic firms may establish production facilities outside of the East-North Central area to gain lower labor and utility costs. For example, Nissan chose to build a plant in Tennessee. Third, domestic firms are closing inefficient and unneeded plants. Table 66 summarizes the factors considered in locating parts-supplier plants.

Automotive plant closings primarily affect employment in the East-North Central region, because automobile production is concentrated there. Ongoing and future losses of automobile-related employment in this region are largely a reflection of the structural changes in the auto industry described earlier in this chapter, although there will continue to be cyclical changes

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[11] Ibid.

[12] U.S. Department of Commerce, *1981 U.S. Industrial Outlook* (Washington, D.C: Department of Commerce, 1981).

[13] MacLennan and O'Donnell, op. cit.

[14] Patricia Hinsberg, "Study Finds Imports Create U.S. Jobs," *Automotive News*, Aug. 20, 1979.

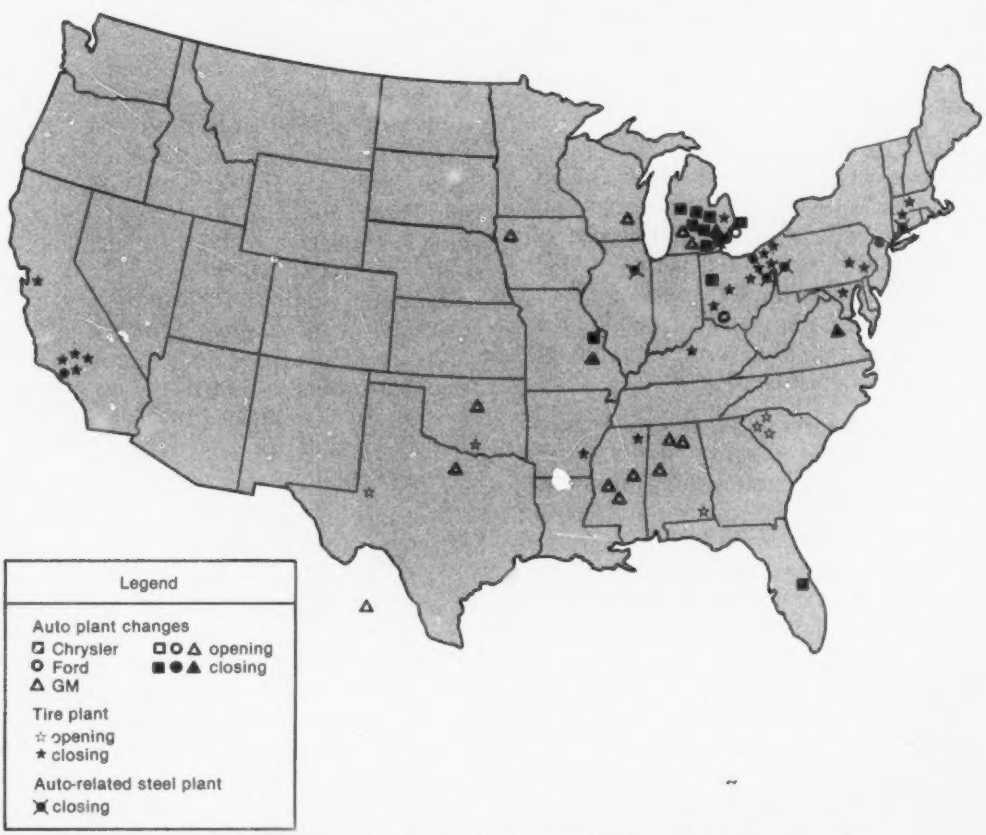
[15] Department of Transportation, op. cit.

[16] Department of Commerce, op. cit.

[17] "GM May Chop Another 19,000 Salaried Jobs," *Automotive News*, Mar. 2, 1981.

[18] *Wall Street Journal*, January 1981.

Figure 20.—Auto, Steel, and Tire Plant Changes, 1975-80



SOURCE: U.S. Department of Transportation, "The U.S. Automobile Industry, 1980," DOT-P-10-81-02, p. xviii, January 1981.

Table 66.—Factors to Consider in Locating Parts-Supplier Plants

Factor	Relative ranking 1970's	Relative ranking 1980's
Availability and cost of skilled labor	1	1
Availability and cost of energy	2	2
State and local taxes, incentives	3	3
Availability and cost of raw materials	2	4
Work ethic of area	4	5
State and local permits, regulations	5	6
Worker's compensation insurance	7	7
Availability and cost of capital	7	8
Right-to-work state (union relations)	6	9
Freight costs	10	10
Quality of living environment	8	11
Community attitude	9	11
Customer service	12	11
Available land	11	12

SOURCE: Arthur Andersen & Co. and the Michigan Manufacturers Association, *Worldwide Competitiveness of the U.S. Automotive Industry and Its Parts Suppliers During the 1980s*, February 1981.

in automobile-related employment. Because of local and regional employment dependence on one industry—motor vehicles—other businesses (such as retail and service establishments) and their employment also suffer as employment in the local population declines.

Unemployment and out-migration will jeopardize other businesses and strain local tax bases, and Michigan will be especially vulnerable. Loss of employment, population, and business recently induced Moody's Investers Service, Inc., to lower bond ratings for Akron, Ohio, which has depended on the tire and rubber industry for its economic vitality; bond ratings for other auto-dependent cities have also been lowered.

CLAIMS INFORMATION
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4
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Photo credit: Michigan Employment Security Commission

Shifts in plant location associated with investments in fuel efficiency may create unemployment problems in traditional manufacturing centers

SOCIAL IMPACTS OF SYNFUELS DEVELOPMENT

Overview

The principal social consequences of developing a synthetic fuels industry arise from large and rapid population increases and fluctuations caused by the changing needs of industry for employees during a facility's useful life. Such population changes disproportionately affect small, rural communities that have limited capacity to absorb and manage the scale of growth involved; these types of communities characterize the locations where oil shale and many coal deposits are found.

In general, whether the consequences of growth from synfuels development will be beneficial or adverse will depend on the ability of communities to manage the stresses which accompany rapid change. Although impacts can be generally characterized, the extent and nature of their occurrence will be site-specific depending on both community factors (size, location, tax base) and technology-related factors (the location, size, number, and type of synfuels facilities; the rate and timing of development; and associated labor requirements).

Growth will tend to concentrate in established communities where services are already available, if they are within commuting distance to synfuels facilities. New towns may be established to accommodate growth in some areas. Large towns will serve as regional service centers. Isolated communities will more likely experience greater impacts than areas where well-linked communities can share the population influx. Energy conversion facilities which are sited near mines will result in the greatest concentration of local impacts.

Most synfuels production from oil shale in the Nation will be concentrated in four Western counties, affecting about a dozen communities in sparsely populated areas of northwestern Colorado and northeastern Utah, and eventually southwestern Wyoming. These communities are widely separated, are connected by a skeletal transportation network, and have had historically small populations. Oil shale cannot be economically transported offsite because of the large quantities of shale involved per barrel of product.

Coal presents a more flexible set of options than oil shale with respect to the location of conversion facilities in relation to mines. The coal used for synfuels production will most likely be dispersed among all the Nation's major coal regions.

In the West, coal sites will be in the oil shale States (Colorado, Utah, and Wyoming) as well as in Montana, North Dakota, and New Mexico. Most of the increase in Western coal production for synfuels will be in Wyoming and Montana.[19] Midwestern sites will most likely be in Illinois, western Kentucky, and Indiana. The coal counties to be most severely affected in Appalachia will be in rural parts of southwestern Pennsylvania, southern West Virginia, and eastern Kentucky. Parts of Illinois will also be affected. In central Appalachia, communities are typically small, congested, and in rural mountain valleys.

The major differences between the Eastern and Western coalfields, in general, are that in the West, counties are larger, towns are smaller and more scattered, the economic base is more diversified, more land is under Federal jurisdiction, water is relatively more scarce, and the terrain is less rugged and variable. To the extent that coal is transported, there could be additional environmental and safety hazards, noise, and disruption or fragmentation of communities, farms, and ranch lands.

The social consequences of producing synthetic fuels from biomass are discussed in detail in a previous OTA report, *Energy From Biological Processes*. Unlike the social consequences associated with fossil fuels, the social impacts of biomass arise from production rather than processing. For example, 90 percent of the employment impacts from biomass are expected from cultivation and harvesting (mostly forestry).

Manpower Requirements

Manpower requirements for synfuels production are generally of two types: 1) labor is required for the construction of energy facilities and supporting service infrastructures, and 2) workers are needed for the operation and maintenance of facilities. As discussed in chapter 8, the ability to attract and retain an adequate labor force—particularly experienced chemical engineers and skilled craftsmen, who are already in short supply—could become a constraint on synfuels development.

Construction manpower requirements for single projects lead to large, rapid, yet temporary, increases in the local population. The construction phase usually lasts 4 to 6 years, peaking over a 2- to 4-year period as construction activities near completion.[20] The shorter the scheduled construction period, the higher the peak labor force.[21] Labor requirements will change significantly during the construction phase, in terms of both size and occupational mix. Labor requirements for the daily, routine operation and maintenance of a plant are relatively stable during the useful life of the facility; scheduled yearly and major maintenance work would cause only brief increases in the operations labor force.

Estimates of manpower requirements for generic 50,000 barrel per day (bbl/d) synthetic fuel plants are shown in table 67. They are highly uncertain, in large part because of the lack of experience with commercial-size plants. In addition, major components of uncertainty in the construction manpower estimates include such unpredictable situations as regulatory delays, lawsuits, delays in the receipt of materials, labor unrest, and the weather; and major components of uncertainty in the estimates of operations manpower relate to the age of the plant, maturity of the technology, and novelty of the plant design.

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[19] E. J. Bentz & Associates, Inc., "Selected Technical and Economic Comparisons of Synfuel Options," contractor report to OTA, April 1981.

[20] Ibid.

[21] Peter D. Miller, "Stability, Diversity, and Equity: A Comparison of Coal, Oil Shale, and Synfuels," in *Supporting Paper 5: Sociopolitical Effects of Energy Use and Policy*, CONAES, Washington, D.C., 1979.

Even for well-known technologies such as coal-fueled electric powerplants, initial estimates of the peak construction labor force required for selected rural-sited plants have varied from about 50 to 270 percent of the actual peak levels.[22] This range of uncertainty may be applicable to the estimates of construction manpower requirements for synfuels plants in general, but should prove to be overly broad when considering a specific technology. The uncertainty surrounding requirements for operational manpower is expected to be narrower, perhaps on the order of ± 25 percent.[23]

The estimates shown in table 67 are plant-gate employment requirements; other synfuels-related activities such as mining, beneficiation, and transportation are not included unless indicated. The manpower requirements for these additional activities will be site-specific and could alter the relative ordering of alternative technologies. For example, on the national average, production per miner per day is approximately three times greater in surface mines than in underground mines. This ratio can be expected to vary, depending on many factors including types of methods and equipment used and geology for underground mining, and geology and environmental considerations for surface mining.[24]

Population Growth

Local population will grow where synfuels are produced because workers directly employed at the synfuels plants, employees in secondary industries and services, and accompanying families will move into these areas. Population growth rates will depend on the nature of the area where the plant is located and on the phase of plant development.

Estimates of population growth due to synfuels development usually assume that for each new worker entering an area, the population increases between three and five persons.[25] The demand

Table 67.—Manpower Requirements for a 50,000 bbl/d Generic Synfuels Plant

	Liquefaction			
	Direct	Indirect	Coal gases	Oil shale
Total construction (person-years)	11,000	20,000	11,000	11,000[a]
Peak construction (persons)	3,500	6,800[b]	3,800	3,500[a]
Operations and maintenance (persons)	360[c] 2,300[d]	360[c] 3,800[d]	360[c] 1,200[d]	2,000[e]

[a] Surface retorting will generally have higher construction manpower requirements than modified in-situ processes.
[b] Manpower requirements of 17,000 persons have been projected by Fluor Corp. based on a SASOL type coal conversion plant ("A Fluor Perspective on Synthetic Liquids: Their Potential and Problems").
[c] Daily, routine O&M requirments (E. J. Bentz & Associates, Inc., "Selected Technical and Economic Comparisons of Synfuels Options," April 1981).
[d] Annual aggregation of scheduled yearly and major maintenance work. Technology specific (Bechtel National, Inc., "Production of Synthetic Liquids From Coal: 1980-2000," December 1979).
[e] Oil shale requirements include mining. Modified in-situ (MIS) processes will generally have higher O&M requirements than surface retorting (e.g., MIS involves an ongoing mining process).

SOURCE: Office of Technology Assessment.

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[22] John S. Gilmore, "Socioeconomic Impact Management: Are Impact Assessments Good Enough to Help?" paper presented at the Conference on Computer Models and Forecasting Impacts of Growth and Development, University of Alberta, Jasper Park Lodge, Alberta, Apr. 21, 1980 (revised June 1980).

[23] George Wang, Bechtel Group, Inc., personal communication.

[24] The average national production per miner per day was 8.38 tons in underground mines and 25.78 tons in surface mines for bituminous and lignite in 1978. Nationwide, productivity varied: for underground mining, from approximately 2 to 15 average tons per miner per day and, for surface mining, from approximately 7 to 98 average tons per miner per day. (Department of Energy, Energy Information Administration, *Bituminous Coal and Lignite Production and Mine Operations—1978,* Energy Data Report, June 16, 1980.)

[25] As an example, White, et al., use a population/employment multiplier of 3.0 for the construction phase and 4.0 for the operation phase (*Energy From the West,* Science and Public Policy Program, University of Oklahoma, prepared for the Environmental Protection Agency, March 1979). Miller uses a uniform "conservative" population/employment multiplier of 5.0 (see footnote 21 above).

for support services in nearby communities increases with the absolute size of the work force during the peak construction period. The larger the work force required during peak construction relative to that required for operations and maintenance, the greater the likelihood that nearby communities will experience large population fluctuations.

In general, if several facilities are located in the same area, the impacts from population growth and fluctuation could be disproportionately large unless construction and operation activities are coordinated; on the other hand, population growth associated with construction can be stabilized if an indigenous construction work force develops.*

Estimates of population increases associated with the fossil synfuels development scenarios presented in chapter 6 are shown in table 68. On a regional basis, population growth associated with oil shale will be concentrated in only several counties in the Mountain Region (see fig. 21). Population increases associated with coal-based synfuels will be dispersed throughout the Nation, with the East North Central experiencing the biggest population increases and the West South Central experiencing the smallest population increases.

Table 69 shows energy-related population growth during the last decade in selected communities. In small communities, and in sparsely populated counties and States, energy-related population growth could represent a significant proportion of future population growth. For example, official population projections by the Colorado West Area Council of Governments (CWACOG) show increases by 1985, relative to 1977, of up to 400 percent in Rio Blanco County (1977 special census population was 5,100) and 300 percent in Garfield County (1977 special census population was 18,800), assuming the industry develops according to the 1979 plans of companies active in the area.

Table 68.—Estimates of Regional Population Growth Associated With Fossil Synfuels Development[a] (thousands)

	1990	1995	2000
Low estimate:			
South Atlantic	4-6	12-20	30-51
East North Central	14-24	46-76	115-192
East South Central	5-9	17-28	42-71
West North Central	5-9	17-28	42-71
West South Central	2-3	6-10	15-25
Mountain:			
Coal	7-12	23-38	58-96
Shale	66-110	90-150	81-135
Total	103-173	211-350	383-641
High estimate:			
South Atlantic	11-18	33-55	86-144
East North Central	33-56	105-174	275-458
East South Central	11-18	33-55	86-144
West North Central	17-29	54-90	141-235
West South Central	5-8	15-25	39-65
Mountain:			
Coal	19-32	60-100	122-203
Shale	132-220	213-355	108-180
Total	228-381	513-854	857-1,429

[a] Estimates are relative to 1985 (for plants coming online in the year shown) and are based on OTA's development scenarios presented in ch. 8. Population multipliers of 3 and 5 were applied to develop the ranges shown. Aggregated estimates should not be extrapolated to determine the ability of any State or locality to absorb this population.

[b] Production is distributed among the regions, according to the low and high scenario distributions used in the Bechtel report for, respectively, the low and high scenarios developed herein (Bechtel National, Inc., December 1979). It is further assumed that direct and indirect liquids will be represented equally. Only daily, routine O&M requirements are included.

Regional estimates are for coal processes unless other wise indicated.

SOURCE: Office of Technology Assessment.

Under CWACOG's high-growth scenario (500,000 bbl/d in 1990 and 750,000 bbl/d in 1995 and 2000), increases of up to 800 percent in Rio Blanco County and 350 percent in Garfield County are projected.[26] In three counties in Kentucky where the construction of four major synfuels plants had recently been planned to commence (H-Coal, SRC-I, W. R. Grace, and Texas Eastern), the expected maximum number of synfuels workers (excluding accompanying family members) was projected to increase 1980 population levels by about 3 percent in Daviess County (1980 census population was 86,000) to over 30 percent in Breckinridge County (1980 census population was 17,000) and over 50 percent in Henderson County (1980 census population was 41,000); population increases during the operation phase

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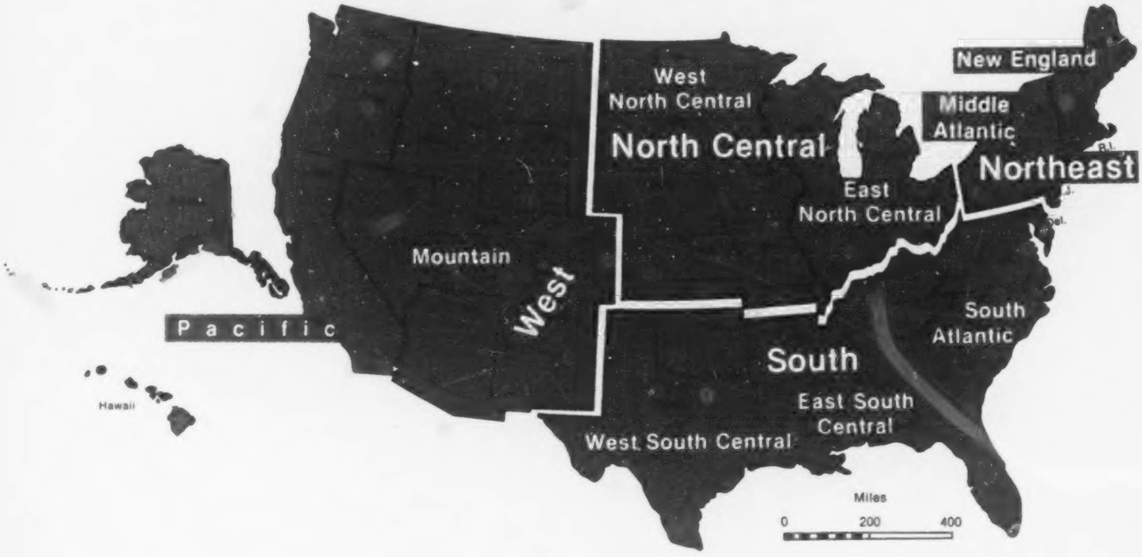
*A succession of projects in an area should lead to an indigenous and more stable construction manpower work force, depending on whether workers perceive a permanence of industrial expansion in the area. Some proportion of the construction work force may also be employed in operations and maintenance activities once construction is completed.

[26] *An Assessment of Oil Shale Technologies,* OTA-M-118 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1980).

Figure 21.—Census Regions and Geographic Divisions of the United States


New England
West
North Central
Middle
Atlantic
North Central
Northeast
R.I.
N.J.
Del.
East
North Central
Mountain
West
Pacific
South
Atlantic
South
East South
Central
West South Central
Hawaii
Miles
0
200
400

SOURCE: U.S. Department of Commerce, Bureau of the Census.

Table 69.—Population Growth in Selected Communities, 1970-80

State	City	Energy resource impact[a]	Population[b]		Percent increase	
			1970	1980	Total	Average annual (compounded)
West Virginia	Buckhannon, Upshur County (Union District)	coal	248	587	136.7	9.0
Kentucky	Caseyville, Union County	coal	23	43	87.0	6.5
Utah	Huntington, Emergy County	coal, powerplant	857	2,316	170.2	10.5
	Orangeville, Emery County	coal, powerplant	511	1,309	156.2	9.9
	Helper, Carbon County	coal	1,964	2,724	38.7	3.3
Wyoming	Douglas, Converse County	coal, uranium, oil, gas	2,677	6,030	125.3	8.5
	Gillette, Campbell County	coal	7,194	12,134	68.7	5.4
	Rocksprings, Sweetwater County	coal, oil, gas, trona, powerplant, uranium	11,657	19,458	66.9	5.3
North Dakota	Washburn, McLean County	coal, powerplant	804	1,767	119.8	8.2
	Beulah, Mercer County	coal, powerplant	1,344	2,878	114.1	7.9
Montana	Forsyth, Rosebud County	coal, powerplant	1,873	2,553	36.3	3.2
	Hardin, Big Horn County	coal	2,733	3,300	20.7	1.9
	Colstrip, Rosebud County[c]	coal, powerplant	<200	3,500	1,650.0	33.1
Colorado	Craig, Moffat County	coal, powerplant	4,205	8,133	93.4	6.8
	Rifle, Garfield County	oil shale, minerals, coal	2,150	3,215	49.5	4.1
	Hayden, Routt County	coal, powerplant	763	1,720	125.4	8.5

[a] Identified by the Department of Community Development within the respective States.
[b] Bureau of the Census, *1980 Census of Population and Housing, Advance Reports.*
[c] Estimates by Sunlight Development, Inc.

SOURCE: Office of Technology Assessment.

were projected to be respectively 0.4, 4, and 15 percent (excluding accompanying family members).[27] Table 70 shows statewide population estimates, based on an extrapolation of only demographic trends, for some of the States that are most likely to experience population increases from synfuels development.

Small rural communities (under 10,000 residents) that experience high population growth rates are vulnerable to institutional breakdowns. Such breakdowns could occur in the labor market, housing market, local business activities, public services, and systems for planning and financing public facilities. Symptoms of social stress (such as crime, divorce, child abuse, alcoholism, and suicide) can be expected to increase.

The term "modern boomtown" has been used to describe communities that experience strains on their social and institutional structure from sudden increases and fluctuations in the population. Communities are also concerned about the possibility of a subsequent "bust." Large fluctuations in population size could lead to a situation where a community expands services at one point in time only to have such services underutilized in the future if demands fail to materialize or be sustained.

Private Sector Impacts

The principal social gains from synfuels development in the private sector are increased wages and profits; direct and secondary employment opportunities will be created and expanded; disposable income will increase; profits from energy investments should be realized; and local trade and service sectors will be stimulated. The ability of the private sector to absorb growth will depend, in large part, on the degree of economic diversification already present. Western communities, in general, have more diversified economies and broader service bases than those in the East, where many communities (as in central Appalachia) have historically been economically dependent on coal.

Many private sector benefits, however, will not be distributed to local communities, at least during the early periods of rapid growth. For example, synfuels development would be located in areas where the required manpower skills are already scarce; unemployment in local communities may thus not be significantly lowered unless local populations can be suitably trained. Where synfuels development competes with other sectors for scarce labor, fuel and material inputs, and capital resources, traditional activities may be curtailed and the price of the scarce resources inflated. Local retail trade and service industries may experience difficulties in providing and expanding services to keep pace with demands, re-

Table 70.—Statewide Population Estimates

State	Total State population 1980[a] (millions)	Statewide population percent increase 1970-80		Projected State population 2000[b]	
		Total	Annual compounded	1990	2000
Kentucky	3.66	13.7	1.3	4.08	4.43
West Virginia	1.95	11.8	1.1	2.08	2.20
Colorado	2.89	30.7	2.7	3.50	4.00
Montana	0.79	13.3	1.3	0.90	0.98
North Dakota	0.65	5.6	0.5	0.70	0.73
Wyoming	0.47	41.6	3.5	0.54	0.60
Utah	1.46	37.9	3.3	1.73	1.95

[a] Bureau of the Census, *1980 Census of Population and Housing, Advanced Reports.*

[b] Bureau of the Census, *Illustrative Projections of State Populations by Age, Race, and Sex: 1975 to 2000.* Projected estimates are from Series II-B which assumes a continuation from 1975 through 2000 of the civilian non-college interstate migration patterns by age, race, and sex observed for the 1970-75 period. Has been corrected by the percent difference between the 1980 projections and the 1980 census. Note that these projections are extensions of recent trends with respect to demographic factors only.

SOURCE: Office of Technology Assessment.

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[27] C. Gilmore Dutton, "Synfuel Plants and Local Government Fiscal Issues," memorandum to the Interim Joint Committee on Appropriations and Revenue, Frankfort, Ky., Dec. 18, 1980.

cruiting and retaining employees, and competing with out-of-State concerns. Both the Eastern and Western sites for synfuels development have generally depended on imported capital, and profits to and reinvestments of the energy companies are likely to be distributed to locations remote from plant sites.

High local inflation rates often accompany rapid growth, due to both excess demand for goods and services and high industrial wage rates. Local inflation penalizes those whose wages are independent of energy development and those on fixed incomes.[28]

Housing can be a major problem for the private sector in areas that grow rapidly from synfuels development: the existing housing stock is usually already in short supply and often of poor quality; local builders often lack the experience and capability to undertake projects of the large scale required; shortages of construction financing and mortgage money are common; and land may not be available for new construction because of terrain, land prices, or overall patterns of ownership. Housing shortages have already led to dramatic price increases in the Western oil shale areas. The need for temporary housing for construction workers aggravates housing supply problems, and mobile homes are often used by both temporary and permanent workers.

Public Sector Impacts

Communities experiencing rapid growth are vulnerable to the overloading of public facilities and services, due both to large front-end capital costs and to constraints which limit a community's ability to make the necessary investments in a timely fashion.* Ability of a community to absorb and provide for a growing population will be community-specific and depend on many factors—such as the size of the predevelopment tax base, availability of developable land, existing social and institutional structure, extent and rate of growth of demand for public services, local planning capabilities and management skills, and political attitudes.

In the long run, local governments should benefit from expanded tax bases arising from the capital intensity of energy facilities and the establishment of associated economic activity. In the aggregate, sufficient additional tax revenue should be produced to pay for the upgrading and expansion of public facilities and services as required for the growing population.[29] In the short run, however, raising local revenues under conditions of rapid growth is often made difficult because of the unequal distribution of incurred costs and revenue-generating capacity among different levels of government.

For example, energy development activities are typically sited outside municipal boundaries, with the result that revenues go to the county, school district, and/or State. However, the population growth accompanying this energy development, and hence the need for services, typically occurs within cities and towns that do not receive additional revenues from the new industry. The separation between taxing authority and public service responsibility can also occur across State lines. In addition, the availability of local tax revenues can lag behind the need for services, because industrial taxes are often based on assessed property values and are not received until full plant operation.* Note also that the total tax burden on the mineral industry and the proportion of State taxes distributed to localities vary from State to State.

There is no clear consensus on the cost of providing additional new public facilities and services in communities affected by energy development. The economics of the decision to expand from an existing service base, or to build a new town, will depend on such factors as the availability of land, accessibility to employment, extent and state of the existing infrastructure, and industry/local community relations. Costs will also depend on site characteristics, design choices, and the anticipated size and rate of growth of population.

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[28] *An Assessment of Oil Shale Technologies*, op. cit.

*Investments in the public sector can be constrained by, as examples, existing tax bases, debt limitations, bonding capacity, and the 2- to 5-year leadtime typically required for planning and implementing services. In addition, ceilings are often established on the rate of expansion of local government budgets, and there is a tendency either not to tax or to undervalue undeveloped mineral wealth.

[29] *Management of Fuel and Nonfuel Minerals in Federal Lands*, OTA-M-88 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

*Note that mobile homes generate little, if any, property taxes; and local governments have had difficulty in providing services to such sites.

As an example, the Colorado Department of Local Affairs has developed detailed estimates which project that the total capital costs of providing totally new services would be approximately $10.8 million (1980 dollars) per 1,000 new residents; annual operating costs for public facilities are estimated to average about $1 million per 1,000 new residents.[30] Approximately 85 percent of the total capital costs is estimated to be required for water supply and sewerage, municipal and county roads, and schools. Other facilities and services included in these estimates are for libraries, administration, fire protection, public health and safety, detention, solid waste, parks and recreation, and shop and maintenance. These cost estimates appear to be low, based on the experience gained in developing the new town of Battlement Mesa, which is part of the Colony Oil Shale Project and which would accommodate a population of about 25,000.[31] Note that these estimates are for total costs; i.e., no cost

Photo credit: Battlement Mesa, Inc.

Synfuels development will require the creation of new communities in sparsely populated areas

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[30] "Fourth Annual Report to the Colorado State Legislature, 1981, Summary and Status Report of the Mineral Lease and Severance Tax Fund," Division of Impact Assistance, Department of Local Affairs, State of Colorado, January 1981.

[31] C. E. McGehee, Battlement Mesa, Inc., personal communication.

recovery or other funding/revenue mechanisms have been applied.

Health care is particularly vulnerable to overloading from rapid growth because rural communities often have inadequate health services prior to development and experience difficulties in attracting and retaining physicians. Synfuels development will change the health care needs of local communities because of the influx of young families, the increase in sources of social stress, and new occupational environments that will give rise to special health care needs. Hospital facilities as well as health, mental health, and social services will be required. Educational facilities are also likely to be overloaded. Both Eastern coal communities and Western oil shale communities are presently having difficulty in attracting and retaining personnel and in funding the provision and expansion of facilities and programs.

Public sector dislocations caused by synfuels development on Indian lands could be more severe than on other rural areas. Tribes have limited ability to generate revenues, there will be large cultural differences between tribal members and workers who immigrate to an area to work on a project, and land has religious significance to some tribes and individual landownership is commonly prohibited (so that, for example, conventional patterns of housing development may not be possible).

Most reservations are also sparsely populated, with few towns, and public services and facilities are severely inadequate and overburdened. Significant amounts of coal are owned by Indians in New Mexico and Arizona, lesser amounts in Montana, North and South Dakota, and Colorado. Although in the aggregate current coal leases represent only a fraction of the total coal under lease, Indian leases are important because of their size and coherence. About 8 percent of the oil-shale mineral rights in the Uinta Basin are owned by Indians, but most of the associated deposits are of low grade.[32]

Managing Growth

Unmanaged growth, although not well understood, appears nevertheless to be a leading source of conflict and stress associated with energy development. All involved parties—the Federal, State, and local governments; industry; and the public—have an interest in and are contributing in varying degrees to growth management by providing planning, technical, and financial assistance to communities experiencing the effects of synfuels development. These mechanisms, which vary among States in terms of their scope, detail, and development, are discussed in detail in previous OTA reports.[33] [34] [35] in general, the effectiveness of existing mechanisms has yet to be tested in the face of rapid and sustained industrial expansion. Major issues to be resolved include who will bear the costs of and responsibilities for both anticipating and managing social impacts, and how up-front capital will be made available when needed to finance public services.

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[32] U.S. Geological Survey, *Synthetic Fuels Development, Earth-Science Considerations,* 1979.

[33] *An Assessment of Oil Shale Technologies,* op. cit.

[34] *Management of Fuel and Nonfuel Minerals in Federal Lands,* op. cit.

[35] *The Direct Use of Coal: Prospects and Problems of Production and Combustion,* OTA-E-86 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979).

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Environment, Health, and Safety Effects and Impacts

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Chapter 10

Environment, Health, and Safety Effects and Impacts

INTRODUCTION

There are major differences in the risks to public health and the environment associated with the alternative approaches to reducing the dependence of the U.S. transportation sector on foreign oil. Depending on the level of development, the *production and use of synthetic fuels* imply massive increases in mining (and agriculture and forestry for biomass), construction and operation of large conversion plants producing substantial quantities of waste products (some of which are toxic), and fuel products that may be different from the fuels now in commerce and that may thus represent different risks in handling and use.

Electrification of autos would require large increases in electric power production, which in turn imply major increases in powerplant fuel use and emissions. Also, the use of electric cars would decrease the use of conventional vehicles and thus yield reductions in vehicular emissions as well as changes in vehicle materials and operating characteristics.

Increased automotive fuel efficiency would involve changes in vehicle size, materials, operating characteristics, and emissions. All the strategies would reduce the use of petroleum that would otherwise have been imported, and adverse effects associated with the strategies should be partially offset by the resulting environmental benefit of reductions of oil spills and other hazards.

This section identifies potential effects on the environment and human health of these three alternative (or complementary) approaches to reducing or eliminating oil imports. Because of significant uncertainties in the precise characteristics of the technologies to be deployed, their potential emissions and the control levels possible, and future environmental regulations and other important predictive factors, the approach of this evaluation is relatively informal and qualitative. We attempt to put the alternatives into reasonable perspective by identifying both a range of potential effects and, given the availability of controls and incentives to use them, the most likely environmental problems of deployment. The major emphasis in the discussion of synthetic fuels is on coal-based technologies. OTA has recently published reports on biomass energy[1] and oil shale,[2] both of which contain environmental assessments.

AUTO FUEL CONSERVATION

Some measures taken to improve the fuel economy of light-duty vehicles might have significant effects on automobile safety and the environment. Major potential effects include changes in vehicle crashworthiness due to downsizing and weight reduction, environmental effects from changes in materials and consequent changes in mining and processing, and possible air-quality effects from the use of substitutes for the spark-ignition engine.

Motor Vehicle Safety

The shift to smaller, lighter, more fuel-efficient cars has led to heightened concern about a possible increase in traffic injuries and fatalities. Part of this concern stems from evidence that occupants of smaller cars have been injured and killed at rates considerably higher than the rates associated with larger cars. The National Highway Traffic Safety Administration (NHTSA) has recently estimated[3] that a continuing shift to smaller vehicles could result in an additional 10,000 traffic deaths per year (with total annual road fatalities of 70,000) by 1990 unless compensating measures are taken.

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[1] *Energy From Biological Processes,* OTA-E-124 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, July 1980).

[2] *An Assessment of Oil Shale Technologies,* OTA-M-118 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, June 1980).

In light of these concerns, OTA examined available evidence on the relationship between vehicle size and occupant safety in today's auto fleet, and reviewed some attempts—including the NHTSA estimate—to extrapolate this evidence to a future, downsized fleet.

Occupant Safety and Vehicle Size in Today's Fleet

Much of the current concern about the safety of small cars is based on statistical analysis of national data from the Fatal Accident Reporting System (FARS), which contains information on fatal motor vehicle accidents occurring in the United States. For example, an analysis of FARS data on automobile occupant deaths conducted by the Insurance Institute for Highway Safety (IIHS) (fig. 22) shows that deaths per registered vehicle increase substantially as vehicle size (measured by length of wheelbase) decreases.[4] Furthermore, this trend occurs for both single- and multiple-vehicle crashes. The trend is so strong that the annual occupant deaths per registered small subcompact are more than twice as high as the rate for full-size cars—3.5 per 10,000 cars compared with 1.6 per 10,000.

The relationships illustrated in figure 22 tempt one to conclude that small cars are much less safe than large cars in virtually all situations. For a variety of reasons, however, the information in the figure must be interpreted with care. First, the recent crash tests sponsored by NHTSA[5] (new cars were crashed head-on into a fixed barrier at 35 miles per hour) seemed to indicate that the differ-

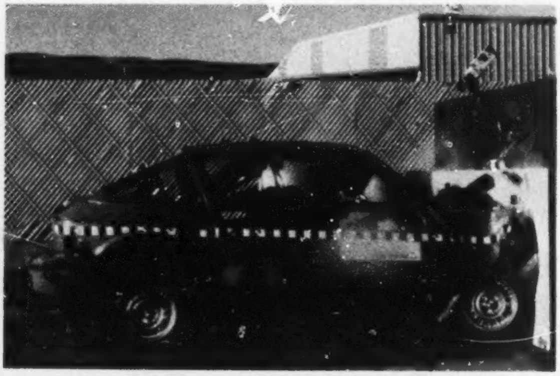
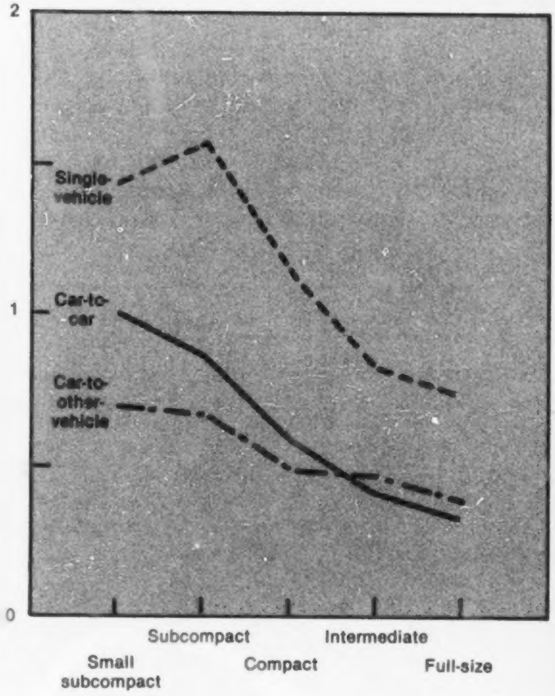


Photo credit: National Highway Traffic Safety Administration

Crash tests sponsored by the National Highway Traffic Safety Administration are an important source of information for understanding the mechanics of crashes and evaluating auto safety features

Figure 22.—Passenger-Car Occupant Death per 10,000 Registered Cars by Car Size and Crash Type; Cars 1 to 5 Years Old in Calendar Year 1980



SOURCE: Insurance Institute for Highway Safety.

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[3] National Highway Traffic Safety Administration, *Traffic Safety Trends and Forecasts*, DOT-HS-805-998, October 1981.

[4] Insurance Institute for Highway Safety, *Status Report*, vol. 17, No. 1, Jan. 5, 1982.

[5] The crash tests are described in several references. A useful, clear reference is "Which Cars Do Best in Crashes?" in the April 1981 issue of *Consumer Reports*. Also see M. Brownlee, et al., "Implications of the New Car Assessment Program for Small Car Safety," in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, Wolfsburg, Germany, Oct. 21-24, 1980, NHTSA report.

ences in expected occupant injuries between vehicles in the same size class—i.e., differences caused by factors other than size—can be greater than any differences between the size classes. Importantly, the results imply that relatively minor changes in engineering and design, such as inexpensive improvements in the steering column and changes in the seatbelt mechanisms, can produce improvements in vehicle crashworthiness that may overwhelm some of the differences caused by size alone. The results of the tests can be applied only to occupants wearing seatbelts (11 percent of total occupants[6]), however, and only to new cars in collisions with fixed objects.

Another reason to be cautious is that the IIHS analysis may be overlooking the effect of variables other than car size. For example, the age of drivers and occupants is a critical determinant of fatality rates. Younger drivers tend to get into more serious accidents,[7] and younger occupants are less likely than older ones to be killed or seriously injured in otherwise identical crashes.[8] Because the average age of drivers and occupants is not uniform across car size classes—it is believed that smaller cars tend to have younger drivers and occupants—the observed differences in fatality rates may be functions not only of the physical characteristics of the cars but also of differences in the people in those cars.

Other variables that should be considered in interpreting injury and fatality statistics include safety belt usage (drivers of subcompact cars have been reported to use seatbelts at a significantly higher rate than drivers of intermediate and large cars[9]), the average number of occupants per car, and differences in maneuverability and braking capacity (i.e., crash avoidance capability) between big and small cars.*

Several analyses have tried to account for the effect of some of these variables.[10] However, these analyses use different data bases (e.g., State data such as that available from North Carolina, and other national data bases such as the National Accident Sampling System and the National Crash Severity Study), different measures of vehicle size (wheelbase, the Environmental Protection Agency (EPA) interior volume, weight, etc.), different formulations of safety (e.g., deaths per 100,000 registered vehicles, deaths per vehicle-mile driven, deaths per crash), and in addition their data reflect different time frames. Few analyses correct for the same variables. Consequently, it is extremely difficult to compare these analyses and draw general conclusions.

Also, credible data on total accident rates for all classes of cars, and more detailed data on accident severity, are not widely available. This type of data would allow researchers to distinguish between the effects of differences in crashworthiness and differences in accident avoidance capability in causing the variations in fatalities measured in the FARS data base. For example, studies of accident rates in North Carolina indicate that subcompacts are involved in many more accidents than large cars.[11] Consequently, the relationship between fatalities per registered vehicle and car size, and that between fatalities *per crash* and car size could be significantly different for this data set, with the latter relationship indicating less dependence between safety and vehicle size than appears to be the case in the former. Unfortunately, such data are available only in a few jurisdictions and cannot be used to draw nationwide conclusions.

Finally, the existing data base reflects only current experience with small cars. In particular, the data reflect no experience with the class of extremely small sub-subcompacts that currently are sold in Japan and Europe but not in the United States. It is conceivable that widespread introduction of such cars into the U.S. fleet, triggered by their lower sales prices or by renewed oil price increases, could have severe safety consequences. NHTSA engineers are concerned that occupants of sub-subcompacts might be endangered not only by the increased deceleration forces that are the inevitable danger to the smaller vehicle in multicar crashes, but also by problems of managing crash forces and maintaining passenger-compartment integrity that are encountered in designing and building cars this small.[12]

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[6] R. H. Stephenson and M. M. Finkelstein, "U.S. Government Status Report," in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[7] H. M. Bunch, "Smaller Cars and Safety: The Effect of Downsizing on Crash Fatalities in 1995," HSRI Research Review (University of Michigan), vol. 9, No. 3, November-December 1978.

[8] Ibid.

[9] Stephenson and Finkelstein, op. cit.

*The effect of improved crash avoidance capability and other safety factors may be perverse. To the extent that drivers may take more chances in reaction to their perception of increased safety, they can negate the effectiveness of safety improvements. The tendency of drivers of large cars to use seatbelts at a lower rate than drivers of small cars may be an indicator of such a reaction.

[10] A variety of these are described in J. R. Stewart and J. C. Stutts, "A Categorical Analysis of the Relationship Between Vehicle Weight and Driver Injury in Automobile Accidents," NHTSA report DOT-HS-4-00897, May 1978.

[11] J. R. Stewart and C. L. Carroll, "Annual Mileage Comparisons and Accident and Injury Rates by Make, Model," University of North Carolina Highway Safety Research Center.

Despite these problems, some conclusions about the relationship between vehicle size and safety can be drawn. For example, the strong positive relationship between vehicle size and safety in *all accidents combined* and in *car-to-car collisions* has been confirmed in virtually all analyses.[13] However, the size/safety relationship does not appear to be as "robust" for single-car collisions, which accounted for about half of all passenger-car occupant fatalities in 1980. Although several studies conclude that there is a strong positive relationship between car size and safety in this class of accidents,[14] and the IIHS analyses show a very strong relationship,[15] some studies have concluded that this positive relationship disappears among some size classes when the data are corrected for driver age and other variables.[16] However, even these studies show that subcompacts fare worse than all other size classes in single-vehicle accidents.[17]

Forecasting Future Trends in Auto Safety

Attempts to forecast the effects on traffic safety of a smaller, more fuel-efficient fleet—a result of further downsizing within each size class as well as a continued market shift to smaller size classes—are confronted with severe analytical difficulties. First, if the forecast is to account for the effects of important vehicle and driver-related variables, the forecasters must predict how these variables will change in the future—e.g., for each size class, forecasters must predict future values of average driver age, vehicle miles driven, occupancy rates, seatbelt usage, etc. And they must either estimate future size dimensions in each car class and the number of vehicles in each class in the fleet, or else postulate these values. Second, forecasters must construct a credible model that describes the relationship between traffic safety (e.g., injury and fatality rates) and key vehicle and driver-related variables in such a way that the model will remain valid over the time period of the forecast.

The models used by NHTSA[18] and others[19] to project future safety trends generally use simple statistical representations of the relative risk of accidents or injuries and fatalities. The traffic fatality projections examined by OTA all relied on accident data that included older design automobiles even though few such vehicles are likely to remain in the fleet when the date of the projection arrives.

In particular, NHTSA's widely disseminated estimate of 10,000 additional annual traffic deaths by 1990[20] assumed that exposure to fatality risk is a function only of vehicle weight and the number of registered vehicles in each weight class. No account is taken of the effect of recent vehicle design changes, age and behavior of drivers, differences in crash avoidance capabilities, differences in annual vehicle-miles driven and vehicle occupancy rate between various automobile size classes, and other variables. Similar shortcomings exist in the other projections. *The resulting projections of future changes in traffic injuries and fatalities should be considered as only rough, first-order estimates.*

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[12] J. Kanianthra, Integrated Vehicle Research Division, NHTSA, personal communication, March 1982.

[13] Stewart and Stutts, op. cit.

[14] For example, several studies cited in Stewart and Stutts, op. cit.; also, J. H. Engel, Chief, Math Analysis Division, NHTSA, "An Investigation of Possible Incompatibility Between Highway and Vehicle Safety Standards Using Accident Data," staff report, April 1981; also, J. O'Day, University of Michigan Highway Safety Research Institute, personal communication, March 1982.

[15] IIHS, op. cit.

[16] Stewart and Stutts, op. cit.

[17] Ibid.

[18] NHTSA, op. cit. The model briefly described in this report appears to be similar to the forecasting model used in J. N. Kanianthra and W. A. Boehly, "Safety Consequences of the Current Trends in the U.S. Vehicle Population," in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op.cit.

[19] W. Dreyer, et al., "Handling, Braking, and Crash Compatibility Aspects of Small Front-Wheel Drive Vehicles," Society of Automotive Engineers Technical Paper Series 810792, June 1981. Also, Bunch, op. cit. Also, J. Hedlund, "Small Cars and Fatalities—Comments on Volkswagen's SAE Paper," internal NHTSA memorandum, Feb. 4, 1982.

[20] NHTSA, op. cit.

Because of the weaknesses in available quantitative projections of future fatality rates, OTA examined current injury/fatality data and other sources for further evidence of whether or not downsizing and a mix shift to smaller size classes would have a significant effect on safety. In particular, the following observations are important to answering this question:

1. A safety differential between occupants of small and large cars in multiple-car collisions does not necessarily imply that reducing the size of all cars will result in more deaths in this class of accidents. Although available data clearly imply that reducing a vehicle's size will tend to increase the vulnerability of that vehicle's occupants in a car-to-car collision, the size reduction also will make the vehicle less dangerous to the vehicle it collides with. Under some formulations of accident exposure and fatality risk, these two factors may cancel each other out. For example, Volkswagen has calculated the effect of increasing the proportion of subcompacts in today's fleet. Using FARS data and forecasting assumptions that are well within the plausible range, Volkswagen concluded that an increase in subcompacts would actually lead to a *decrease* in traffic fatalities in car-to-car collisions.[21] Other models using different formulations and data bases might come to different conclusions. For example, models using traffic safety data from North Carolina probably would arrive at a different result. In this historical data set, subcompacts colliding with subcompacts have been found to have a considerably greater probability of causing a fatality than collisions between two full-size cars.[22] Presumably, models using this data set would be likely to forecast that a trend toward more subcompacts would lead to an increase in car-to-car crash fatalities.
2. If small cars are less safe than large cars in single-car accidents, then a decrease in the average size of cars in the fleet with no compensatory improvements in crashworthiness clearly should imply an increase in injuries and fatalities in this class of accidents. As just discussed, some studies suggest that a consistent relationship between size and safety does not exist for compact, midsize, and full-size cars in single-car accidents.[23] On the other hand, subcompacts do fare worse than the other classes in these studies.[24] Consequently, if these studies are correct, a general downsizing of the fleet might have only a small effect on fatalities in single-car accidents, while a drastic shift to very small cars could cause a large increase in such fatalities.

The results of these studies may not be widely applicable. Other studies observe a definite size/safety relationship across all size classes.[25] And some factors tend to favor this alternative conclusion. For example, the higher seatbelt usage in smaller cars should tend to make small cars appear safer in the raw injury data, and thus tend to hide or weaken a positive size/safety relationship. Taking differences in seatbelt usage into account might expose or strengthen such a relationship.[26] Also, analysis of FARS data that includes only vehicles up to 5 years old produces a stronger size/safety relationship than analysis of the whole fleet.[27] Most studies use the whole fleet, but the more limited data set might prove to be better for a projection of the future because it reflects only newer-design automobiles. Finally, as discussed in chapter 5, the larger crush space and passenger compartment volume available to the larger cars should give them, at least theoretically, a strong advantage in the great majority of accidents. On the other hand, an opposing factor favoring those studies showing less dependence between vehicle size and crashworthiness is the limited evidence of increasing accident rates with decreasing car sizes.[28] This offers a reason other than

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[21] Dreyer, et al., op. cit.

[22] K. Digges, "Panel Member Statement," Panel on ESV/RSV Program, in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[23] Stewart and Stutts, op. cit.

[24] Ibid.

[25] Supra 14.

[26] Stephenson and Finkelstein, op. cit.

[27] Based on a comparison of IIHS's analysis, op. cit., and Engel's analysis, op. cit.

[28] Stewart and Carroll, op. cit.

(or in addition to) differences in crashworthiness for the differences in fatalities among the various auto size classes.

3. Although most arguments about downsizing and traffic safety have focused on vehicle occupants, the inclusion of pedestrian fatalities will affect the overall argument. About 8,000 pedestrians were killed by motor vehicles in 1980,[29] and analysis of FARS data indicates that pedestrian fatalities per 100,000 registered cars increase as car size increases[30]—i.e., reducing the average size of cars in the fleet might decrease pedestrian fatalities because of the reduced "aggressiveness" of smaller cars towards pedestrians. If policy concern is for total fatalities, this effect should lessen any overall adverse safety effect of downsizing the fleet.
4. Much of the available data implies that traffic fatalities will rise if the number of collisions between vehicles of greatly different weights increases. This points to three dangers from a downsized fleet. First, for a limited period of time, the number of collisions of this sort might increase because of the large number of older, full-size cars left in the fleet. This problem should disappear within a decade or two when the great majority of these older cars will have been scrapped. Second, a more permanent increase in fatalities could occur if large numbers of very small sub-subcompacts—cars not currently sold in the U.S. market—were added to the passenger vehicles fleet. The potential for successful large-scale sales of such vehicles will depend on their prices—they may be significantly less expensive than current subcompacts—as well as future oil prices and public perceptions of gasoline availability. Third, car-truck collisions, which today represent a significant fraction of occupant fatalities (car-to-other-vehicle accidents account for about 25 percent of total occupant fatalities[31]), may cause more fatalities unless the truck fleet is downsized as well. Subcompacts fare particularly poorly in car-truck collisions, and a large increase in the number of vehicles in this size class could create substantial problems.

The available statistical and physical evidence on auto safety suggest that a marked decrease in the average vehicle size in the automobile fleet may have as a plausible outcome an increase in vehicle-occupant fatalities of a few thousand per year or more. This outcome seems especially likely during the period when many older, heavier vehicles are still on the road. Also, such an outcome seems more likely if the reduction in average size comes mainly from a large increase in the number of very small cars in the fleet, rather than from a more general downsizing *across* the various size categories in the fleet.

The evidence is sufficiently ambiguous, however, to leave open the possibility that only a minor effect might occur. And, as discussed in the next section, improvements in the safety design of new small vehicles (possibly excluding very small sub-subcompacts) probably could compensate for some or all of the adverse safety effect associated with smaller size alone. Some automobile analysts feel that significant safety improvements are virtually inevitable, even without additional Government pressures. For example, representatives of Japanese automobile companies have stated[32] that the present poor record of Japanese cars in comparison with American small cars[33] is unacceptable and will not be allowed to continue. Major improvements in Japanese auto safety would seem likely to force a response from the American companies. Also, General Motors has begun to advertise the safety differentials between its cars and Japanese models, an indication that American manufacturers may have decided that safety *can* sell. On the other hand, because of its severe financial difficulties, the industry may be reluctant to pursue safety improvements that involve considerable capital expenditures.

Safer Design

Increases in traffic injuries and fatalities need not occur as the vehicle fleet is made smaller in size. Numerous design opportunities exist to improve vehicle safety, and some relatively simple measures could go a long way towards compensating for adverse effects of downsizing and shifts to smaller size classes.

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[29] NHTSA, *Fatal Accident Reporting System 1980.*

[30] Based on an analysis of data presented in Engel, op. cit.

[31] NHTSA, op. cit.

[32] Reported in the April 1981 *Consumer Reports,* op. cit.

[33] Ibid., and IIHS, op. cit.

Increased use of occupant restraint systems would substantially reduce injuries and fatalities. NHTSA analysis indicates that the use of air bags and automatic belts could reduce the risk of moderate and serious injuries and fatalities by about 30 to 50 percent.[34]

Simple design changes in vehicles may substantially improve occupant protection. As noted in evaluations of NHTSA crash tests, design changes that are essentially cost-free (changing the location of restraint system attachment) or extremely low cost (steering column improvements to facilitate collapse, seatbelt retractor modifications to prevent excessive forward movement)[35] appear to be capable of radically decreasing the crash forces on passenger-car occupants.

A variety of further design modifications to improve vehicle safety are available. As demonstrated in the NHTSA tests,[36] there are substantial safety differences among *existing* cars of equal weight. One important feature of the safer cars, for example, is above-average length of exterior structure to provide crush space. Also, the Research Safety Vehicle Program sponsored by the Department of Transportation shows that small vehicles with safety features such as air bags, special energy-absorbing structural members, antilaceration windshields, improved bumpers, doors designed to stay shut in accidents, and other features can provide crash protection considerably superior to that provided by much larger cars.

Two forms of new automotive technology introduced for reasons of fuel economy could also have important effects on vehicle safety. First, the incorporation of new lightweight, high-strength materials may offer the automobile designer new possibilities for increasing the crashworthiness of the vehicle. Because some of the plastics and composite materials currently have problems resisting certain kinds of transient stresses, however, their use conceivably could degrade vehicle safety unless safety remains a primary consideration in the design process. Second, the use of electronic microprocessors and sensors, which is expected to become universal by 1985 to 1990 to control engine operation and related drivetrain functions, could eventually lead to safety devices designed to avoid collisions or to augment driver performance in hazardous situations.

Modifications to roadways can also play a significant role in improving the safety of smaller vehicles. For example, concrete barriers and roadway posts and lamps designed to protect larger vehicles have proven to be hazards to subcompacts[37] in single-vehicle crashes, and redesign and replacement of this equipment could lower future injury and fatality rates.

Mining and Processing New Materials

Aside from the beneficial effects of downsizing on the environmental impacts of mining—by reducing the volume of material required—vehicle designers will use new materials to reduce weight or to increase vehicle safety. Table 71 shows four candidates for increased structural use in automobiles and the amount of weight saved for every 100 lb of steel being replaced.

It appears unlikely that widespread use of these materials would lead to severe adverse impacts. Magnesium, for example, is obtained mostly from seawater, and the process probably has fewer pollution problems than an equivalent amount of iron and steel processing. Most new aluminum

Table 71.—Material Substitutions for Vehicle Weight Reductions

Structural material	Weight saved/100 lb steel replaced
Magnesium	75
Fiberglass-reinforced composites	35-50
Aluminum	50-60
High-strength low-alloy steel	15-30

SOURCE: M. C. Flemming and G. B. Kenney, "Materials Substitution and Development for the Light-Weight, Energy-Efficient Automobile," OTA contractor report, February 1980.

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[34] R. J. Hitchcock and C. E. Nash, "Protection of Children and Adults in Crashes of Cars With Automatic Restraints," in Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[35] Brownlee, et al., op. cit.

[36] Ibid.

[37] IIHS, op. cit.

probably would be obtained by importing bauxite ore or even processed aluminum, rather than expanding domestic production. If kaolin-type clays are used for domestic production, waste disposal problems could be significant; however, the cost of producing aluminum from this source currently is too high to make it economically worthwhile.

Use of high-strength low-alloy steel will likely lead to slightly lowered iron and steel production because of the higher strength of this material, with a positive environmental benefit. Finally, the use of plastics and reinforced composites would substitute petrochemical-type processing for iron and steel manufacture, with an uncertain environmental tradeoff.

Air Quality

Regulation of automobile emissions under the Clean Air Act of 1970 (Public Law 91-614) and subsequent amendments has sharply reduced the amount of pollutants from automobile exhaust in the atmosphere. Assuming that present standards and proposed reductions in permissible levels of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x are met, the aggregate of automobile emissions by 1985 will be roughly half of what they were in 1975 despite an increase of 25 percent in the number of cars on the road and a corresponding rise in total miles of vehicle travel.* By 2000, if the 1985 standards have been maintained and complied with, the aggregate of automobile emissions of HC, CO, and NO_x will be 33, 32, and 63 percent of today's levels, respectively. Particulate emissions would be about one-half of today's levels—and possibly much lower, depending on the progress in control of particulate emissions from diesels.

The reductions expected by 1985 will have been brought about by a combination of two basic forms of emission control technology—methods of limiting the formation of pollutants through control of fuel-air mixture, spark timing, and other conditions of combustion in the engine, and systems to remove pollutants from the exhaust before it is discharged into the atmosphere. The effectiveness of both techniques has been greatly enhanced by the advent of electronic engine controls in recent years.

By 1985, when electronic engine controls will be virtually universal in passenger cars, the mandated levels of 3.4 grams per mile (gpm) CO, 0.41 gpm HC, and 1.0 gpm NO_x can probably be met by spark-ignition engines with little or no penalty in fuel economy beyond that associated with the lower engine compression ratios dictated by (low-octane) lead-free gasoline.* And although this fuel penalty may be charged to the control of CO, HC, and NO_x emissions because lead-free gasoline is required to protect catalytic converters, the reduction in lead additives to gasoline may also be justified on the basis of its beneficial effect in reducing lead emissions and, consequently, the level of lead in human tissue. Assuming that reducing lead in gasoline is desirable even without the catalytic converter requirement, the much-argued tradeoff between fuel economy and emissions that seemed so compelling in the 1970's is unlikely to remain a major issue with the spark-ignition engine by the last half of the 1980's.

A shift to still smaller vehicles and the introduction of new engines (and substantial increases in the use of current diesel technology) may affect the tradeoff between air quality and control costs. Because lower vehicle weights and lesser performance requirements will allow substantially smaller engines, the grams per mile emission standards should be easier to meet for most engine types. And, although manufacturers can be expected to respond to this opportunity by cutting back on emission controls, there will be an enhanced potential for eventually lowering emissions still further. On the other hand, some of the engines—e.g., the gas turbines and diesels—may pose some control problems, with NO_x and particulates especially.

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*These projections, based on an earlier study by OTA[38] have been adjusted to account for more recent data on automobile use and the lower projected growth rates used in this study.

[38] *Changes in the Future Use and Characteristics of the Automobile Transportation System,* OTA-T-83 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, February 1979).

*Although high-octane lead-free gasoline can be, and is, manufactured, the fuel savings it might allow from higher compression engines may be counterbalanced by additional energy required for refining. The exact energy required to produce higher octane lead-free gasoline will be very specific to the refinery, feedstock, and refinery volumes.

Table 72 briefly describes some of the emissions characteristic of current and new engines for light-duty vehicles. The potential emission problem with diesels appears to be the major short-term problem facing auto manufacturers today in meeting vehicle emission standards. There appears to be substantial doubt that diesels can comply with both NO_x and particulates standards without some technological breakthrough, because NO_x control, already a problem in diesels, conflicts with particulate control. This problem is especially significant because diesel particulates are small enough to be inhaled into the lungs and contain quantities of potentially harmful organic compounds.

The effect on human health of a substantial increase in diesel particulate emissions is uncertain, because clear epidemiologic evidence of adverse effects does not exist and because there is doubt about the extent to which the harmful organics in the emissions will become biologically available—i.e., free to act on human tissue[*]—after inhalation.[39] However, a sharp increase in the number of diesel automobiles to perhaps 25 percent of the market share, which appears possible by the mid-1990's, probably should be considered to represent a significant risk of adverse health effects unless improved particulate controls are incorporated or unless further research provides firmer evidence that diesel particulates produce no special hazard to human health.

Table 72.—Emissions Characteristics of Alternative Engines

Current spark ignition.—Meets currently defined 1983 standards.

Current (indirect injection) diesel.—Can meet CO and HC standards, but NO_x remains a problem. NO_x control conflicts with HC and particulate control. Future particulate standards could be a severe problem.

Direct-injection diesel.—Meets strictest standards proposed for HC and CO. NO_x limit 1 to 2 g/mile depending on vehicle and engine size. Possible future problems with particulates, odor, and perhaps other currently unregulated emissions.

Direct-injection stratified-charge.—Needs conventional spark-ignition engine emission control technology to meet strict HC/CO/NO_x standards. Better NO_x control than diesel. In some versions particulates likely to be problem.

Gas turbine-free shaft.—Attainment of 0.4 g/mile NO_x limit a continuing problem, appears solvable, maybe with variable geometry. Other emissions (HC, CO) no problem.

Single shaft.—Same basic characteristics as comparable free shaft. Better fuel economy may help lower NO_x emissions.

Single shaft (advanced).—NO_x emissions aggravated because of higher operating temperatures.

Stirling engine (first generation).—Early designs have had some NO_x problems, but should meet tightest proposed standards on gasoline, durability probably no problem, emissions when run on other fuels not known.

SOURCE: Adapted from: J. B. Heywood, "Alternative Automotive Engines and Fuels: A Status Review and Discussion of R&D Issues," contractor report to OTA, November 1979.

ELECTRIC VEHICLES

The substitution of electric vehicles (EVs) for a high percentage of U.S. automobiles and light trucks may have a number of environmental effects. The reduction in vehicle-miles traveled by conventional gasoline- and diesel-powered vehicles will reduce automotive air pollution, whereas the additional requirements for electricity will increase emissions and other impacts of power generation. Changes in materials use may have environmental consequences in both the extractive and vehicle manufacturing industries. The use of large numbers of batteries containing toxic chemicals may affect driver and public health and safety. The different noise characteristics of electric and internal combustion engines imply a reduction in urban noise levels, while differences in size and performance may adversely affect driving safety. Finally, there may be a variety of lesser effects, for example, safety hazards caused by installation and use of large numbers of charging outlets.

Power Generation

As discussed in chapter 5, utilities should have adequate reserve capacity to accommodate high levels of vehicle electrification without adding new powerplants. For example, if the utilities could use load control and reduced offpeak prices to confine battery recharging to offpeak hours, half of all light-duty vehicular traffic could be electrified today without adding new capacity. Given the probable constraints on EVs, however, a 20-percent share probably is a more reasonable target for analysis.*

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[*] Initially, the organics adhere to particulate matter in the exhaust. In order for them to be harmful, they must first be freed from this matter. In tissue tests outside the human body ("in vitro" tests), they were not freed, i.e., they did not become biologically active. This may be a poor indicator of their activity inside the body, however.

[39] Health Effects Panel of the Diesel Impacts Study Committee (H. E. Griffin, et al.), National Research Council, *Health Effects of Exposure to Diesel Exhaust,* National Academy of Sciences, Washington, D.C., 1980.

The effects on emissions of a 20-percent electrification of vehicular travel are mixed but generally positive. If present schedules for automotive pollution control are met and utilities successfully restrict most recharging to offpeak hours, this level of electrification would, by the year 2010, lead to the following changes in emissions** compared with a future based on a conventional fossil fuel-powered transportation system:

- less than a 1-percent increase in sulfur dioxides (SO_2),
- about a 2-percent decrease in NO_x,
- about a 2-percent decrease in HC,
- about a 6-percent decrease in CO, and
- little change in particulates.[40]

The positive effects on air quality may in reality be more important than these emission figures imply. The addition of emissions due to electricity production occurs outside of urban areas, and the pollution is widely dispersed, while the vehicle emissions that are eliminated occur at ground level and are quite likely to take place in dense urban areas. Thus, the reduction in vehicular emissions should have a considerably greater effect on human exposure to pollution than the small increase in generation-related emissions. Also, any relaxation of auto emissions standards will increase the emissions reductions and air quality benefits associated with "replacement" of the (more polluting) conventional autos. On the other hand, future improvements in automobile emission controls—certainly plausible given progress during the past decade—might decrease the air quality benefits of electrification.*

Other effects of increased electricity demand must also be considered. Most importantly, a 20-percent electrification of cars will lead to substantial increases in utility fuel use, especially for coal. Although the extent of increased coal use will depend on the distribution of EVs, if the vehicles were distributed uniformly according to population, coal would supply about two-thirds of the additional power necessary in 2010,[41] requiring the mining of about 38 million additional tons per year.** If the EVs replaced gasoline-powered cars getting 55 mpg, the gasoline savings obtained by the coal-fired electricity—about 36 billion gal/yr—could also have been obtained by turning the same amount of coal into synthetic gasoline.***

Resource Requirements

EVs will use many of the same materials, in similar quantities, as conventionally powered vehicles, but there will be some differences which may create environmental effects. EVs, for example, will require more structural material than their conventional counterparts because of the substantial weight of the batteries (at least with existing technology). More importantly, the batteries themselves will require some materials in quantities that may strain present supply. Table 73 shows the increase in U.S. demand for battery materials for 20-percent electrification of light-duty vehicular travel by 2000.

The effect on the environment of increases in materials demand is difficult to project because the increased demand can be accommodated in a number of ways. In several cases, although U.S.

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*As noted elsewhere, however, this is still an extremely optimistic market share even for the long term, unless battery costs are sharply reduced and longevity increased, or gasoline availability decreases.

**Assuming existing emission regulations for powerplants.

[40] W. M. Carriere, et al., *The Future Potential of Electric and Hybrid Vehicles*, contractor report by General Research Corp. to OTA, forthcoming.

*It is equally reasonable to speculate about future improvements in powerplant emission controls. For example, more stringent controls on new plants as well as efforts to decrease SO_2 emissions from existing plants in order to control acid rain damages could *increase* the benefits of electrification.

[41] Ibid.

**Assumptions: 12,000 Btu/lb coal; vehicle energy required = 0.4 kWh/mile at the outlet; total 2010 vehicle miles = 1.55 trillion miles, 20 percent electric; electrical distribution efficiency = 90 percent; generation efficiency = 34 percent.

***Assuming a synfuels conversion efficiency of coal into gasoline of 50 percent.

Table 73.—Increase in U.S. Use of Key Materials for 20 Percent Electrification of Light-Duty Travel (year 2000)

Battery type	Material	Percent increase[a]
Lead-acid	Lead	31.2
Nickel-iron	Cobalt	18.2
	Lithium	14.3
	Nickel	21.3
Nickel-zinc	Cobalt	31.8
	Nickel	34.3
Zinc-chloride	Graphite	50.0
Lithium metal sulfide	Lithium	103.6

[a] Assuming 100 percent of the batteries are of the category shown . . . the percent increases thus are *not additive* for the same materials.

SOURCE: W. M. Carrier, et al., *The Future Potential of Electric and Hybrid Vehicles*, contractor report to OTA by General Research Corp., forthcoming.

and world identified reserves currently are insufficient, increased demand probably will be met by identifying and exploiting new reserves. The environmental effects would then be those of expanding mining and processing in the United States or abroad. In other cases, mining of seabed mineral nodules or exploitation of lower quality or alternative ores (e.g., kaolin-type clays instead of bauxite to produce aluminum) could occur. Supplies of some materials may be made available for cars by substituting other materials for nonautomotive demands.

In general, the potential for finding additional resources and the long-range potential for recycling indicate that major strains on resources—and, consequently, environmental impacts of unusual concern—appear to be unlikely with levels of electrification around 20 or 30 percent. Local areas subject to substantially increased mining activity could, however, experience significant impacts.

Noise

EVs are generally expected to be quieter than combustion-engine vehicles, and electrification should lower urban noise. The effect may not, however, be large. Although automobiles account for more than 90 percent of all urban traffic, they contribute only a little more than half of total urban traffic noise and a lesser percentage of total urban noise. A recent calculation of the effect on noise levels of 100-percent conversion of the automobile fleet to electric vehicles predicts a reduction in total traffic noise of only 13 to 17 percent.[42]

Safety

EVs will affect automotive safety because of their lower performance capabilities and different structural and material configuration. Lower acceleration and cruising speed, for example, could pose a safety problem because it could increase the average velocity differential among highway vehicles and make merging more difficult. Many EVs will be quite small and, as discussed in the section on auto fuel conservation, this may degrade safety. On the other hand, compensating changes in driver behavior or redesign of roads in response to EVs could yield a net positive effect.

Similarly, the net effect of materials differences is uncertain. The strong positive effect of removing a gas tank containing highly flammable gasoline or diesel fuel will be somewhat offset by the addition of the battery packs, which contain acids, chlorine, and other potentially hazardous chemicals. Collisions involving EVs may result in the generation of toxic or explosive gases or the spillage of toxic liquids (e.g., release of nickel carbonyl from nickel-based batteries). Finally, the necessity to charge many of the vehicles in locations that are exposed to the weather creates a strong concern about consumer safety from electrical shock.

Occupational and Public Health Concerns

In addition to the potential danger to drivers (and bystanders) from release of battery chemicals after collisions, there are some concerns about the effects of routine manufacture, use, and disposal of the batteries. Manufacture of nickel-based batteries, for example, may pose problems for women workers because several nickel compounds that may be encountered in the manufacturing process are teratogens (producers of birth defects). Also, because many potential battery materials (lead, nickel, zinc, antimony) are persistent, cumulative environmental poisons, the prevention of significant discharges during manufacture as well as proper disposal (preferably by recycling) must be assured. Finally, routine venting of gases during normal vehicle operations may cause air-quality problems in congested areas.

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[42] W. M. Carriere, General Research Corp., personal communication, June 19, 1981.

These risks do not appear to pose difficult technological problems (most have been rated as "low risk" in the Department of Energy's (DOE) Environmental Readiness Document for EVs[43]) and existing regulations such as the Resource Conservation and Recovery Act provide an opportunity for strict controls, but institutional problems such as resistance to further Government controls on industry obviously could increase the level of risk. Recycling could pose a particular problem unless regulations or scale incentives restrict small-scale operations, which are often difficult to monitor and regulate.

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[43] U.S. Department of Energy, *Environmental Readiness Document, Electric and Hybrid Vehicles, Commercialization Phase III Planning*, DOE/ERD-0004, September 1978.

SYNTHETIC FUELS FROM COAL

Development of a synthetic fuels industry will inevitably create the possibility of substantial effects on human health and the environment from a variety of causes. A 2 million barrels per day (MMB/D) coal-based synthetic liquid fuels industry will consume roughly 400 million tons of coal each year,* an amount equal to roughly half of the coal mined in the United States in 1980. The several dozen liquefaction plants required to produce this amount of fuel will operate like large chemical factories and refineries, handling multiple process and waste streams containing highly toxic materials and requiring major inputs of water and other valuable materials and labor. Transportation and distribution of the manufactured fuels not only require major new infrastructure but are complicated by possible new dangers in handling and using the fuels. Table 74 lists some of the major environmental concerns associated with coal-based synfuels. *Note that the severity of these concerns is sharply dependent on the level of environmental control and management exerted by Government and industry.*

The health and environmental effects of the synfuels fuel cycle can be better understood by dividing the impacts into two kinds. Some of the impacts are essentially identical in kind (though not in extent) to those associated with more conventional combustion-related fuel cycles such as coal-fired electric power generation. These "conventional" impacts include the mining impacts, most of the conversion plant construction impacts, the effects associated with population increases, the water consumption, and any impacts associated with the emissions of environmental residuals such as SO_2 and NO_x that are normally associated with conventional combustion of fossil fuels.

Another set of impacts more closely resembles some of the impacts of chemical plants and oil refineries. These include the effects of fugitive HC emissions and the large number of waste and process streams containing quantities of trace metals, dangerous aromatic HCs, and other toxic compounds. These are referred to as "nonconventional" impacts in this section.

This distinction between "conventional" and "nonconventional" impacts is continued throughout this discussion. In particular, for the conventional impacts, synfuels plants are explicitly compared with coal-fired powerplants. A further understanding of the scale of coal-fired powerplants should allow this comparison to better

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*This corresponds to an average process efficiency of about 55 percent and coal heat content of about 20 × 10^6 Btu/ton. The actual tonnage depends on the energy content of the coals, the conversion processes used and the product mixes chosen. Process efficiencies will vary over a range of 45 to 65 percent (higher if large quantities of synthetic natural gas are acceptable in the product stream), and coal heat contents may vary from 12 million to 28 million Btu/ton.

Table 74.—Major Environmental Issues for Coal Synfuels

Land use and water quality	Air quality	Ecosystems	Safety and health	Other
Mining				
Short- and long-term land use changes, erosion, and uncertainty of reclamation in arid West Aquifer disturbance and pollution Nonpoint source water pollution (acid mine drainage—East; sedimentation—West) Subsidence	Fugitive dust (especially in the West)	Disruption of wildlife habitat and changed productivity of the land Siltation of streams Habitat fragmentation from primary and secondary population growth	Mining accidents Occupational diseases in underground mining (e.g., black lung)	Increased water use for reclamation Coal transportation impacts on road traffic and noise
Liquefaction and refining				
Potential surface and ground water pollution from holding ponds Wastewater discharges (East) Disposal of large amounts of solid wastes Local land use changes Construction on flood plains	Emission of "criteria pollutants" (i.e., NO_x, SO_2, particulates, etc. Fugitive emission of carcinogenic substances Possible release of trace elements Releases during "upset" conditions Possible localized odor problems	Air pollution damage to plants Contributions to acid rain Wildlife habitat fragmentation from population increases Contribution to the "greenhouse" effect	Occupational safety and health risks from accidents and toxic chemicals Carcinogens in direct process intermediates and fuel products	Water availability issues (especially in the West)
Product transport and end-use				
Product spills from trains, pipelines, and storage	Changed automotive exhaust emissions (increase in some pollutants, decrease in others) Increased evaporative emissions from methanol fuels Toxic product vaporization	Acute and chronic damages from spills	Exposure to spills Uncertain effects of trace elements and HCs	Potential change in fuel economy Methanol corrosion and reduction of existing engine longevity

SOURCE: M. A. Chartock, et al., *Environmental Issues of Synthetic Transportation Fuels From Coal*, OTA contractor report, forthcoming.

serve the reader. A 1,000-MWe plant, for example, serves all the electrical needs (including requirements for industry) of about 400,000 people. A plant of this size would be large but not excessively so for a new facility, because many currently planned coal-fired plants are larger than 600 MWe, and the nationwide average capacity of planned units is 433 MWe.[44] Existing plants are, on the whole, much smaller than these new plants, with an average capacity of only 57 MWe.[45] Some existing plants, however, are very large: Arizona Public Service Co.'s Four Corners plant in New Mexico, for example, has a capacity of 2,212 MWe.[46]

This comparison is intended to place the environmental and health impacts of a synfuels plant side by side with the impacts of a technology that may be more familiar to readers. *We stress, however, that this comparison is not relevant to a comparison of coal liquids and coal-based electricity as competing alternatives.*

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[44] R. W. Gilmer, et al., "Rethinking the Scale of Coal-Fired Electric Generation: Technological and Institutional Considerations," in Office of Technology Assessment, *The Direct Use of Coal, Volume II, Part A*, 1979.

[45] Ibid.

[46] Federal Energy Regulatory Commission, *Steam-Electric Plant Air and Water Quality Control Data, Summary Report*, October 1979.

Such a comparison can be made only by carefully considering the end uses for the competing energy forms, which we have not done. For use in automobile travel, however, a synthetic fuel may prove to be as efficient in its utilization of coal energy as a powerplant producing electricity for EVs (see "Electric Vehicles, Power Generation" in this chapter). In this case, to the extent that a synfuels production facility produces fewer (or more) impacts than a powerplant processing the same amount of coal, the impact of the energy-production stage of the "synfuels to motor fuel" fuel cycle may be considered to be environmentally superior (or inferior) to the same stage of the "electric auto" fuel cycle.

It is also stressed that the "nonconventional" effects associated with the toxic waste streams produced by synfuels plants are essentially impossible to quantify at this time, because of significant uncertainties associated with the type and quantity of toxic chemicals produced, the rate at which these chemicals might escape, the effectiveness of control systems, the fate of any escaping chemicals in the environment, and finally, the health and ecological impacts of various exposures to the chemicals.

Because of these uncertainties, there may be a temptation to judge synfuels production mainly on the basis of its "conventional," and more quantifiable, impacts. In OTA's opinion, this is a mistake, because the toxic wastes pose difficult environmental questions and also because the magnitudes of several of the more conventional impacts are themselves quite uncertain.

Mining

A large coal-based synfuels industry will consume a significant portion of U.S. coal output. Although actual coal-production growth during the remainder of this century is uncertain, several sources agree that total production on the order of 2 billion tons per year is possible by 2000.[47] At this level a 2 MMB/D coal synfuels capacity would require roughly 20 percent of total U.S. production in 2000.

The impacts of a mine dedicated to synfuels production should be essentially the same as those from other large mines dedicated to power production and other uses, and thus these impacts fit into the "conventional" category. Although the coal requirement for a unit plant with a 50,000 barrel per day (bbl/d) output capacity—at least 5 million tons per year*—is high by today's standards, mines are already tending towards this size range where it is feasible (e.g., eight mines in the Powder River Basin produced more than 5 million tons of coal each in 1980[48]). On the other hand, it is not clear that the geographic distribution (and thus the distribution of impacts) of synfuels coal production and production for other uses will be similar. Because it is difficult to predict where a future synfuels industry will be located, the nature of any differences between mining for synfuels and mining for other uses is uncertain.

As discussed in another OTA report,[49] although many of coal mining's adverse impacts have been mitigated under State and Federal laws, important environmental and health concerns remain. The major concerns are likely to be *land reclamation failure, acid mine drainage, subsidence of the land above underground mines, aquifer disruption, and occupational disease and injury.* Mining for synfuels conversion will experience all of these impacts, although not at all sites.

The following discussion of mining impacts relies primarily on the OTA report:

Reclamation.—The use of new mining methods that integrate reclamation into the mining process and enforcement of the Surface Mine Control and Reclamation Act (SMCRA) should reduce the importance of reclamation as a critical national issue. However, concern remains that a combination of development pressures and inadequate knowledge may lead to damage in particularly

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[47] *The Direct Use of Coal: Prospects and Problems of Production and Combustion*, OTA-E-86 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, April 1979). Also available from Ballinger Publishers in a March 1981 edition.

*The potential range is about 5 million to 18 million tons per year. The 5-million-ton extreme represents a 65-percent efficient process (not truly a lique faction process because half of its output is syngas; the upper limit of efficiency for processes producing primarily liquids is about 60 percent) using very-high-value (28 million Btu/ton) Appalachian coal. The 18-million-ton extreme represents a 45-percent efficient process using low-energy (12 million Btu/ton) lignite.

[48] *An Assessment of the Development Potential and Production Prospects of Federal Coal Leases*, OTA-M-150 (Washington, D.C.: U.S. Congress, Office of Technology Assessment, December 1981).

[49] *The Direct Use of Coal*, op. cit.

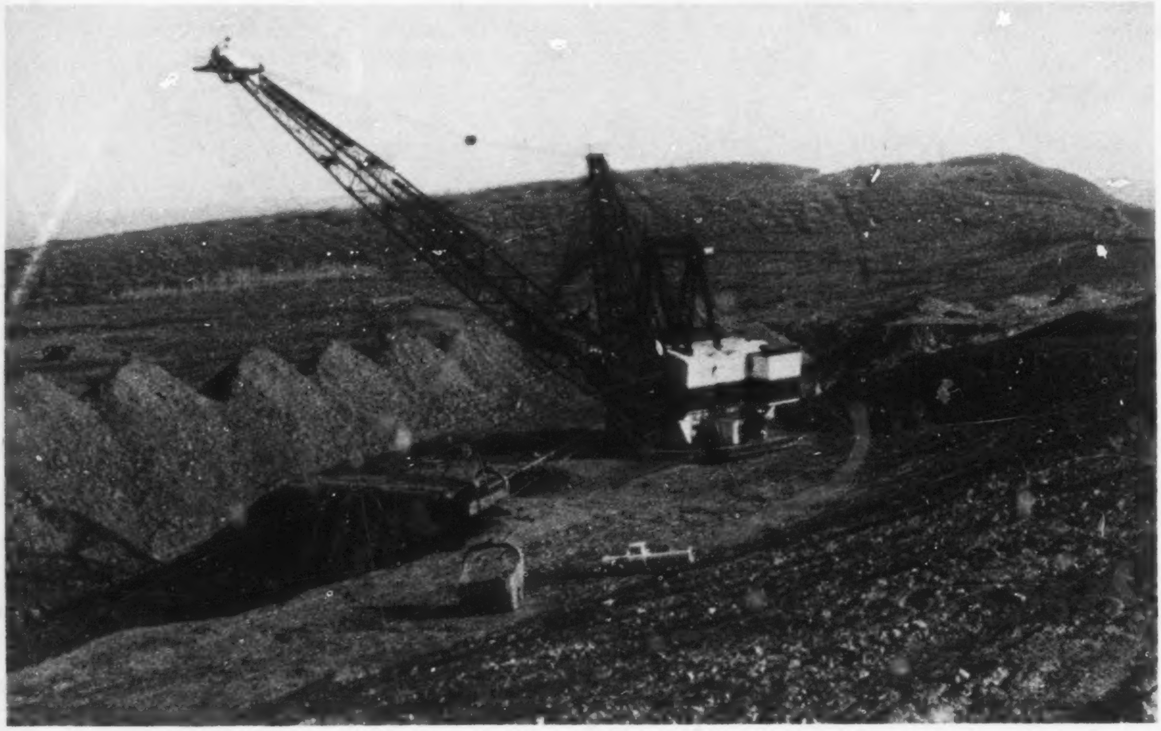

Photo credit: Office of Technology Assessment

Dragline operation: large-scale synfuels production from coal will necessitate a massive expansion of surface mining

vulnerable areas—arid lands and alluvial valley floors in the West, prime farmland in the Midwest, and hardwood forests, steep slope areas, and flood-prone basins in Appalachia. Although most of these areas are afforded special protection under SMCRA, the extent of any damage will depend on the adequacy of the regulations and the stringency of their enforcement. Recent attempts in the Congress to change SMCRA and administration actions to reduce the Office of Surface Mining's field staff and to transfer enforcement responsibilities to State agencies have raised concerns about the future effectiveness of this legislation.

Acid Mine Drainage. Acid mine drainage, if not controlled, is a particularly severe byproduct of mining in those regions—Appalachia and parts of the interior mining region (Indiana, Illinois, Western Kentucky)—where the coal seams are rich in pyrite. The acid, and heavy metals leached into the drainage water by the acid, are directly toxic to aquatic life and can render water unfit for domestic and industrial use. Zinc, nickel, and other metals found in the drainage can become concentrated in the food chain and cause chronic damage to higher animals. An additional impact in severe cases is the smothering of stream bottom-dwelling organisms by precipitated iron salts.

Acid drainage is likely to be a significant problem only with underground mines, and only after these mines cease operating. Assuming strong enforcement of SMCRA, acid drainage from active surface and underground mines should be collected and neutralized with few problems. Only a very small percentage of inactive surface mines may suffer from acid seepage. Underground mines, however, are extremely difficult to seal off from air and water, the causal agents of acid drainage. Some mining situations do not allow adequate permanent control once active mining and water treatment cease. A significant percentage of the mines that are active at present or that will be opened in this century will present acid drainage problems on closure.

In a balancing of costs and benefits, it may not be appropriate to assign to synfuels development the full acid damage associated with synfuels mines, even though these mines will have acid drainage problems. This is because drainage problems may taper off as shallower reserves are exhausted and new mines begin to exploit coal seams that are deeper than the water table. Many of these later mines will be flooded, reducing the oxidation that creates the acid drainage. It is possible that many or most acid drainage-prone mines dedicated to a synfuels plant would have been exploited *with or without synfuels development*.

Subsidence.—Another impact of underground mining that will not be fully controlled is subsidence of the land above the mine workings. Subsidence can severely damage roads, water and gas lines, and buildings; change natural drainage patterns and river flows; and disrupt aquifers. Unfortunately, there are no credible estimates of potential subsidence damage from future underground mining. However, a 2 MMB/D industry could undermine about a hundred square miles of land area (about one-tenth the area of Rhode Island) each year,* most of which would be a potential victim of eventual subsidence.

Subsidence, like acid drainage, is a long-term problem. However, SMCRA does not hold developers responsible for sufficient time periods to ensure elimination of the problem, nor does it specifically hold the developer responsible to the surface owner for subsidence damage. The major "control" for subsidence is to leave a large part of the coal resources—up to 50 percent or more—in place to act as a roof support. There is obviously a conflict between subsidence prevention and removal of the maximum amount of coal. Moreover, the supports can erode and the roof collapse over a long period of time. The resulting intermittent subsidence can destroy the value of the land for development. An alternative mining technique called longwall mining deals with some of these problems by actually promoting subsidence, but in a swifter and more uniform fashion. Longwall mining is widely practiced in Europe but is in limited use in the United States. It is not suitable for all situations.

Aquifer Disruption.—Although all types of mining have the potential to severely affect ground water quantity and quality by physical disruption of aquifers and by leaching or seepage into them, this problem is imperfectly understood. The shift of production to the West, where ground water is a particularly critical resource, will focus increased attention on this impact. As with other sensitive areas, SMCRA affords special protection to ground water resources, but the adequacy of this protection is uncertain because of difficulties in monitoring damages and enforcing regulations and by gaps in the knowledge of aquifer/mining interactions.

Occupational Hazards.—Occupational hazards associated with mining are a very visible concern of synfuels production, because coal workers are likely to continue to suffer from occupational disease, injury, and death at a rate well above other occupations (see table 75), and the total magnitude of these impacts will grow along with the growth in coal production.

The mineworker health issue that has received the most attention is black lung disease, the non-

Table 75.—Fatality and Injury Occurrence for Selected Industries, 1979

	Fatalities		Nonfatal injuries	
	Number	Rate[a]	Number	Rate[a]
Underground bituminous[b]	105	0.09	14,131	12.30
Surface bituminous[b]	15	0.02	2,333	3.47
All bituminous coal[c] (and lignite)	137	0.064	16,464	10.20
Other surface mining[b] (metal, nonmetal, stone, etc.)	97	0.07	8,121	5.82
Petroleum refining[c]	20	0.0011	8,799	5.30
Chemical and allied products[c]	55	0.0025	78,700	7.20
All industries[c]	4,950	0.0086	5,956,000	9.20

[a] Rate per 200,000 worker-hours (100 worker-years).
[b] For all companies.
[c] For companies with 11 or more workers; fatality data include deaths due to job-related accident and illness.

SOURCE: Bureau of Labor Statistics, personal communication, 1981; and Staff, Mine Safety and Health Administration, personal communication, 1981.

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*Assuming half of the coal is produced by eastern and central underground mining, 18,000 acres undermined per 10^{15} Btu of coal.

clinical name for a variety of respiratory illnesses affecting underground miners of which coal workers' pneumoconiosis (CWP) is the most prominent. Ten percent or more of working coal miners today show X-ray evidence of CWP, and perhaps twice that number show other black lung illnesses—including bronchitis, emphysema, and other impairments.[50]

To prevent CWP from disabling miners in the future, Congress mandated a 2-mg/m^3 standard for respirable dust (the small particles that cause pneumoconiosis). However, critics now question the inherent safeness of this standard and the soundness of the research on which it is based. Furthermore, other coal mine dust constituents—the large dust particles (that affect the upper respiratory tract) and trace elements—as well as fumes from diesel equipment also represent continued potential hazards to miners.

Mine safety—as distinct from mine health—has shown a mixed record of improvement since the 1969 Federal Coal Mine Health and Safety Act establishing the Mining Enforcement and Safety Administration was passed. The frequency of mining fatalities has decreased for both surface and underground mines, but no consistent improvement has been seen in the frequency of disabling injuries. Coal worker fatalities numbered 139 in 1977, and disabling injuries approached 15,000.[51] Each disabling injury resulted in an average of 2 months or more of lost time. The number of disabling injuries has been increasing as more workers are drawn to mining and accident frequency remains constant.

As shown in table 75, surface mining is several times safer than underground mining. But some underground mines show safety records equal to or better than some surface mines. Generally, western surface mines are safer than eastern surface mines. As western surface-mine production assumes increasing prominence, accident frequency industrywide is likely to decline when expressed as accidents per ton of output. But this statistical trend may conceal a lack of improvement in safety in deep mines.

Liquefaction

Coal liquefaction plants transform a solid fuel, high in polluting compounds and mineral matter, into liquid fuels containing low levels of sulfur, nitrogen, trace elements, and other pollutants. In these processes, large volumes of gaseous, liquid, and solid process streams must be continuously and reliably handled and separated into end-products and waste streams. Simultaneously, large quantities of fuel must be burned to provide necessary heat and steam to the process, and large amounts of water are consumed for cooling and, in direct liquefaction processes, as raw material for hydrogen production. These processes, coupled with the general physical presence of the plants and their use of a large construction (up to 7,000 men at the peak for a single 50,000 bbl/d plant) and operating force (up to 1,000 workers per plant), lead to a variety of potential pathways for environmental damage.

As noted previously, the following discussion divides impacts into "conventional" and "nonconventional" according to the extent to which the effects resemble those of conventional combustion systems. The discussion does not consider the various waste streams in detail because of their complexity. Appendix 10-A lists the gaseous, liquid, and solid waste streams, the residuals of concern, and the proposed control systems for generic indirect and direct liquefaction systems. DOE's *Energy Technologies and the Environment* handbook,[52] from which appendix 10-A is derived, describes these streams in more detail.

Conventional Impacts

An examination of the expected "conventional" impacts reveals that, with a few exceptions, they are significant mainly because the individual plants are very large and national synfuels development conceivably could grow very rapidly—

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[50] National Institute for Occupational Safety and Health, *National Study of Coal Workers' Pneumoconiosis*, unpublished reports on second round of examinations, 1975. Cited in *The Direct Use of Coal*, op. cit.

[51] Mine Safety and Health Administration, "Injury Experience at All coal Mines in the United States, by General Work Location, 1977," 1978. Cited in *The Direct Use of Coal*, op. cit.

[52] U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

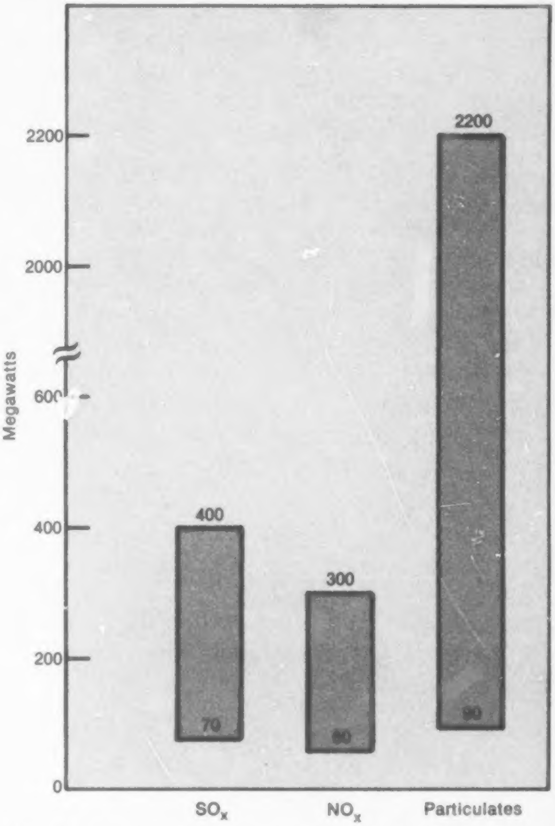
not because the impacts *per unit of production* are particularly large.

Air Quality.—Emissions of criteria air pollutants* from synfuels generally are expected to be lower than similar emissions from a new coal-fired powerplant processing the same amount of coal.[53] A 50,000 bbl/d synfuels plant processes about as much coal as a 3,000 MWe powerplant,** but (as shown in fig. 23) emits SO_2 and NO_x in quantities similar to those of a plant of only a few hundred megawatts or less. For particulates, synfuels plant emissions may range as high as those from a 2,200-MWe plant, but emissions for most synfuels plants should be much lower.

In any case, particulate standards for new plants are quite stringent, so even a 2,200-MWe plant (or a "worst case" synfuels plant) will not have high particulate emissions. CO emissions from synfuels plants are expected to be extremely low, and are likely to be overwhelmed by a variety of other sources such as urban concentrations of automobiles. HC emissions, on the other hand, conceivably could create a problem if fugitive emissions—from valves, gaskets, and sources other than smokestacks—are not carefully controlled. Although the level of fugitive HC emissions is highly uncertain, emissions from a 50,000 bbl/d SRC II plant could be as high as 14 tons/day—equivalent to the emissions from several large coal-fired plants—if the plant's valves and other equipment leaked at the same rate as equipment in existing refineries.[54]

The broad emission ranges shown in figure 23 reflect very substantial differences in emission projections from developers of the various processes. OTA's examination of the basis for these projections leads us to believe that the differences are due less to any inherent differences among the technologies and more to differences in developer control decisions, assumptions about the effectiveness of controls, and coal characteristics. The current absence of definitive environmental standards for synfuels plants will tend to aggravate these differences in emission projections, because developers have no emissions targets or approved control devices to aim at. EPA has been working on a series of Pollution Control Guidance Documents (PCGDs) for the several synfuels technologies in order to alleviate this problem. The proposed PCGDs will describe the control systems available for each waste stream and the level

Figure 23.—Size Ranges of New Coal-Fired Powerplants With Hourly Emissions Equal to 50,000 bbl/day Synfuels Plants



SOURCE: M. A. Chartock, et al., "Environment Issues of Synthetic Tranportation Fuels From Coal," contractor report to OTA, table revised by OTA.

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*"Criteria air pollutants" are pollutants that are explicitly regulated by National Ambient Air Quality Standards under the Clean Air Act. Currently, there are seven criteria pollutants: SO_2, CO, NO_x, photochemical oxidants measured as ozone (O_3), nonmethane HC, and lead.

[53] M. A. Chartock, et al., *Environmental Issues of Synthetic Transportation Fuels From Coal, Background Report,* University of Oklahoma Science and Public Policy Program, report to OTA, forthcoming.

**The actual range is about 2,500 to 3,600 MW for synfuels process efficiencies of 45 to 65 percent, powerplant efficiency of 35 percent, synfuels load factor of 0.9, powerplant load factor of 0.7.

[54] Oak Ridge National Laboratory, *Estimate of Fugitive Hydrocarbon Emissions for SRC II Demonstration Plant,* for U.S. Department of Energy, September 1980. Based on "unmitigated" fugitive emissions.

of control judged to be attainable. However, the PCGDs became embroiled in internal and interagency arguments and apparently may not be completed and published in the foreseeable future.

The air quality effects of synfuels plants on their surrounding terrain vary because of differences in local conditions—terrain and meteorology—as well as the considerable range of possible emission rates. Some tentative generalizations can, however, be drawn from the variety of site-specific analyses available in the literature. One important conclusion from these analyses is that *individual plants* generally should be able to meet prevention of significant deterioration (PSD) Class II limits* for particulates and SO_2 with planned emission controls, although in some cases (e.g., the SRC II commercial-scale facility once planned for West Virginia) a major portion of the limit could be used up.[55] In addition, NO_x and CO emissions are unlikely to be a problem for individual plants in most areas, while regulated HC emissions should remain within ambient air quality guidelines if fugitive HC emissions are minimized.[56]

Restrictions will exist, however, near PSD Class I areas in the Rocky Mountain States and nonattainment areas in the eastern and interior coal regions. Several of the major coal-producing areas of Kentucky and Tennessee are currently in nonattainment status, and siting of synfuels plants in those areas is virtually impossible without changes in current regulations or future air quality improvement.[57] Finally, failure to control fugitive HC emissions conceivably could lead to violations of the Federal short-term ambient standards near the plant because, as noted above, the *potential* emission rate is quite high and because the emissions are released near ground level and will have a disproportionately large effect on local air quality.[58]

Some potential restrictions on siting may be obscured in current analyses by the failure to consider the short-term air quality effects of upsets in the conversion processes. For example, under extreme upset conditions, the proposed (but now canceled) Morgantown SRC II plant would have emitted as much SO_2 in 2 hours as it would have emitted during 4 to 10 days of normal operation.[59] Unfortunately, most environmental analyses of synfuels development have tacitly assumed that control devices always work properly and plant operating conditions always are normal. These assumptions may be inappropriate, especially for the first generation of plants and particularly for the first few years of operating experience.

On a wider geographic scale, most analyses show that the emissions impact of a synfuels industry will be moderate compared with total emissions from all sources. For example, DOE has estimated 1995 emissions from all major sources for particulates, SO_2, and NO_x. Its calculations show that a 1.3 MMB/D synfuels industry (combining gasification, liquefaction, and oil shale) would represent less than 1 percent of national emissions for all three pollutants.[60] A more intensive development—a 1 MMB/D liquefaction industry concentrated in Wyoming, Montana, and North Dakota—would represent a 7.7 percent (particulates), 9.8 percent (SO_2), 32 percent (NO_x), and 1.7 percent (HC) increase over 1975 emissions in a region where existing development—and thus the existing level of emissions—is quite low.[61] These additional emissions are not insignificant, and there has been speculation that high levels of development could cause some acid rain problems in the West, especially from

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*PSD regulations limit the increases in pollution concentrations allowed in areas whose air quality exceeds national ambient standards. Class I areas, generally national parks and other areas where pristine air quality is valued very highly, are allowed only minimal increases. Class III areas are areas designated for industrial development and allowed substantial increases. Most parts of the country presently are designated Class II areas and allowed moderate increases in concentrations. PSD limits are under intense scrutiny by Congress and appear to be primary candidates for change under the Clean Air Act reauthorization.

[55] Chartock, et al., op. cit.

[56] Ibid.

[57] Ibid.

[58] I. L. White, et al., *Energy From the West, Impact Analysis Report Volume I, Introduction and Summary,* U.S. Environmental Protection Agency report EPA-600/7-79-082a, March 1979.

[59] U.S. Department of Energy, *Draft Appendix C of Final Environmental Impact Statement: SRC-II Demonstration Plant, Plant Design and Characterization of Effluents,* 1980.

[60] U.S. Department of Energy, *Synthetic Fuels and the Environment, An Environmental and Regulatory Impacts Analysis,* DOE/EV-0087, June 1980.

[61] Chartock, et al., op. cit.

NO_x.* Nevertheless, if control systems work as planned and facility siting is done intelligently, coal-based synfuels plants do not appear to represent a severe threat to air quality.

Water Use.—Water consumption has also been singled out as a significant impact of a large-scale synfuels industry, especially in the arid West. Synfuels plants are, however, less intensive consumers of water than powerplants consuming similar amounts of coal. A 3,000-MWe plant—which processes about as much coal annually as a 50,000 bbl/d facility—will consume about 25,000 acre-feet of water per year (AFY), whereas the synfuels facility is unlikely to consume more than 10,000 AFY and may consume considerably less than this if designed with water conservation in mind. According to current industry estimates, a standard 50,000 bbl/d facility will consume about as much water as a 640 to 1,300-MWe plant. Using stricter water conservation designs, the facility may consume as much water as a 400- to 700-MWe plant.[62] Achieving an annual synfuels production of 2 MMB/D might require 0.3 million AFY, or only about 0.2 percent of the projected national freshwater consumptive use of 151 million AFY in 2000.[63]

Environmental impacts associated with synfuels water requirements are caused by the water consumption itself and by the wells, pipelines, dams, and other facilities required to divert, store, and transport the necessary water.

The impacts associated with consumption depend on whether that consumption displaces other offstream uses for the water (e.g., the developer may buy a farmer's water rights) or is additive to existing uses. In the former case, the impact is caused by eliminating the offstream use; in displacing farming, for example, the impact may be a reduction in soil salinization that was being caused by irrigation as well as a reduction in water contamination caused by runoff of fertilizers and pesticides. Any calculation of impacts is complicated, however, by the probability that large reductions in economic activities (such as farming) in one area will result in compensating increases elsewhere as the market reacts to decreases in production.

If the water consumption is additive to existing uses, it will reduce downstream flows. In surface streams or tributary ground waters connected to these streams, the consumption may have adverse effects on the ability of the stream to dilute wastes and to support recreation, fishing, and other instream uses downstream of the withdrawal. Also, consumption of ground water, if excessive, may lead to land subsidence and saltwater intrusion into aquifers.

The impacts associated with wells, dams, and other infrastructure may also be significant. Improperly drilled wells, for example, can lead to contamination of drinking water aquifers. Dams and other storage facilities will increase evaporative and other losses (e.g., Lake Powell is underlaid with porous rock and "loses" large amounts of water to deep aquifers). In many cases, the lands submerged by reservoirs have been valuable recreational or scenic areas. In addition, in some circumstances dams can have substantial impacts, including drastic changes in the nature of the stream, destruction of fish species, etc. On the other hand, the ability of dams to regulate downstream flow may help avoid both flooding and extreme low-flow conditions and thus improve instream uses such as recreation and fishing.

Although consumptive water use by synfuels will be small on a national basis, local and even regional effects may be significant. Prediction of these effects is made difficult, however, by a number of factors, including substantial uncertainties in water availability assessments, levels of disaggregation in many assessments that are insufficient to allow a prediction of local and subregional effects, and the variety of alternative supply options available to developers. Water availability considerations for the five major river basins where synfuels development is most likely to occur are discussed in chapter 11.

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*Current understanding of the transformation of NO_x emissions into nitrates and into acid rain is not sufficient to allow a firm judgment to be made about the likelihood of encountering an acid rain problem under these conditions.

[62] H. Gold, et al., *Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States*, U.S. Environmental Protection Agency report EPA-600/7-77-037, April 1977. Assumes powerplant load factor of 70 percent, synfuels load factor 90 percent. Synthoil is used as a baseline liquid fuels plant.

[63] U.S. Water Resources Council, *Second National Water Assessment, The Nation's Water Resources 1975-2000, Volume II*, December 1978.

Work Force and Population Impacts.—The size of the synfuels work force will be large compared with power generation; for a 50,000 bbl/d plant, it is equivalent to the work force that would be needed for powerplants totaling 4,000 to 8,000 Mw (during peak construction) and to plants totaling at least 2,500 MW (during operation)[64] (see ch. 8 for detailed discussion). These high work force values are particularly important for western locations, because significant population increases caused by energy development place considerable stress on semiarid ecosystems through hunting and recreational pressures, inadequate municipal wastewater treatment systems, and limited land use planning.

Summary of Conventional Impact Parameters.—Table 76 provides a capsule comparison of the conventional environmental impacts of synfuels plants and coal-fired plants.

Nonconventional Impacts

The remaining, "nonconventional" impacts of synthetic fuel plants represent substantially different environmental and health risks than do coal-fired plants and other combustion facilities. The conversion of coal to liquid fuels differs from coal combustion in several environmentally important ways. Most importantly, the chemistries of the two processes are considerably different. Liquefaction is accomplished in a reducing (oxygen poor) environment, whereas combustion occurs in an oxidizing environment. Furthermore, the liquefaction reactions generally occur at lower temperatures and usually higher pressures than conventional combustion.

One major result of these chemical and physical differences is that the heavier HCs originally

Table 76.—Two Comparisons of the Environmental Impacts of Coal-Based Synfuels Production and Coal-Fired Electric Generation[a]

Type of impact	A. Coal-fired generating capacity that would produce the same impact as a 50,000 bbl/d coal-based synfuels plant, MWe	B. Side-by-side Comparison of environmental impact parameters		
		3,000 MWe generator	50,000 bbl/d synfuels	Units
Annual coal use	2,500-3,600[b]	6.4-15.0	5.3-17.9	million tons/yr
Annual solid waste	(2,500-3,600) ±[c]	0.9-2.0+	0.6-1.8+	million tons/yr
Annual water use:				acre feet/yr
Current industry estimates	640-1,300	25,000	5,400-10,800	
Conservation case	400-700		3,400-5,900	
Annual emissions:				tons/yr
Particulates	120-2,800	2,700	100-2,500	
Sulfur oxides	90-500	27,000-108,000	1,600-9,900	
Nitrogen oxides	70-400	63,000	1,600-7,800	
Hourly emissions:				lb/hr
Particulates	90-2,200	880	30-800	
Sulfur oxides	70-40	8,800-35,200	500-3,200	
Nitrogen oxides	60-300	20,500	500-2,500	
Peak labor	4,100-8,000	2,550	3,500-6,800	persons
Operating labor	2,500	440	360	persons

[a] In example A, the powerplant uses the same coal as the synfuels plant, New Source Performance Standards (NSPS) apply, SO_x emissions assumed to be 0.6 lb/10^6 Btu. In B, NSPS also apply but SO_x emissions can range from 0.3 to 1.2 lb/10^6 Btu. In both cases, the synfuels plant parameters represent a range of technologies, with a capacity factor of 90 percent and an efficiency range of 45 to 65 percent; the powerplant is a baseload plant, with a capacity factor of 70 percent, efficiency of 35 percent.

[b] In other words, the amount of coal—and thus the amount of mining—needed to fuel a 50,000 bbl/d synfuels plant is the same as that required for a 2,500 to 3,600 MWe powerplant.

[c] A synfuels plant will have about as much ash to dispose of as a coal-fired powerplant using the same amount of coal. It may have less scrubber sludge, but it may have to dispose of spent catalyst material that has no analog in the powerplant . . . thus the ±.

SOURCE: M. A. Chartock, et al., *Environmental Issues of Synthetic Transportation Fuels From Coal, Background Report,* University of Oklahoma Science and Public Policy Program, contractor report to OTA, July 1981.

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[64] I. L. White, et al., *Energy From the West, Energy Resource Development Systems Report, Volume II: Coal,* U.S. EPA report EPA-600/7-79-060b, March 1979. Used for powerplant work force only (for a 3,000-MWe plant, construction peak is 2,545, operating force is 436).

in the coal or formed during the reactions are not broken down as effectively in the liquefaction process as in combustion processes, and thus they appear in the process and waste streams. The direct processes (see ch. 6 for a brief description of the various coal liquefaction processes) and those indirect processes using the lower temperature Lurgi gasifier are the major producers of these HCs; indirect processes using high-temperature gasifiers (e.g., Koppers-Totzek, Shell, Texaco) are relatively free of them.

The liquefaction conditions also favor the formation of metal carbonyls and hydrogen cyanide, which are hazardous and difficult to remove. Trace elements are less likely to totally volatilize and may be more likely to combine with or dissolve in the ash. The solids formed under these conditions will have different mineralogical and chemical form than coal combustion ash, and the solubility of the trace elements, which generally is low in combustion ash, is likely to be different. Consequently, solid waste disposal is complicated by the possibility that the wastes may be more hazardous than those associated with conventional combustion.

Finally, the high pressure of the processes, their multiplicity of valves and other vulnerable components, and, for the direct processes, their need to handle liquid streams containing large amounts of abrasive solids all increase the risk of accidents and fugitive emissions.

The major concerns from the "nonconventional" waste streams are *occupational hazards* from leaks of toxic materials, accidents, and handling of process intermediates, and *ground and surface water contamination* (and subsequent health and ecological damage) from inadequate solid waste disposal, effluent discharges, and leaks and spills.

Occupational Hazards.—Coal synthetic fuel plants pose a range of occupational hazards from both normal operations and upset conditions. Aside from risks associated with most heavy industry, including exposure to noise, dusts, and heat, and falls from elevated areas, synfuels workers will be exposed to gaseous and liquid fugitive emissions of carcinogenic and other toxic materials. During upset conditions, contact with hot gas and liquid streams and exposure to fire and explosion is possible. Table 77 lists some of the potential exposures from coal gasification plants documented by the National Institute for Occupational Safety and Health. Table 78 lists the potential occupational health effects associated with the constituents of indirect liquefaction process streams. Similar exposure and health-effect potentials would exist for any coal liquefaction process.

Although the precise design and operation of the individual plant is a critical factor in determining occupational hazards, there are certain generic differences in direct and indirect technologies that appear to give indirect technologies some advantages in controlling health and safety risks.

The advantages of indirect technologies include the need to separate only gases and liquids (the solids are eliminated in the very first gasification step) in contrast with the gas/liquid/solid phase separation requirements of direct processes; fewer sites for fugitive emissions than the direct processes; lower processing requirements for the process liquids produced (direct process liquids require additional hydrogenation); the abrasive

Table 77.—Potential Occupational Exposures in Coal Gasification

Coal handling, feeding, and preparation.—Coal dust, noise, gaseous toxicants, asphyxia, and fire
Gasifier/reactor operation.—Coal dust, high-pressure hot gas, high-pressure oxygen, high-pressure steam and liquids, fire, and noise
Ash removal.—Heat stress, high-pressure steam, hot ash, and dust
Catalytic conversion.—High-pressure hot gases and liquids, fire, catalyst, and heat stress
Gas/liquids cooling.—High-pressure hot raw gas and liquid hot tar, hot tar oil, hot gas-liquor, fire, heat stress, and noise
Gas purification.—Sulfur-containing gases, methanol, naphtha, cryogenic temperature, high-pressure steam, and noise
Methanol formation.—Catalyst dust, fire, and noise
Sulfur removal.—Hydrogen sulfide, molten sulfur, and sulfur oxides
Gas-liquor separation.—Tar oil, tar, gas-liquor with high concentrations of phenols, ammonia, hydrogen cyanide, hydrogen sulfide, carbon dioxide, trace elements, and noise
Phenol and ammonia recovery.—Phenols, ammonia, acid gases, ammonia recovery solvent, and fire
Byproduct storage.—Tar, oils, phenols, ammonia, methanol, phenol recovery solvent and fire

SOURCE: Adapted from U.S. Department of Health, Education and Welfare, "Criteria for a Recommended Standard . . . Occupational Exposures in Coal Gasification Plants" (Cincinnati: National Institute of Occupational Safety and Health, Center for Disease Control, 1980).

Table 78.—Occupational Health Effects of Constituents of Indirect Liquefaction Process Streams

Constituents	Toxic effects	Stream or area
Inorganic		
Ammonia	Acute: respiratory edema, asphyxia, death Chronic: no evidence of harm from chronic subirritant levels	Gas liquor
Carbon disulfide	Acute: nausea, vomiting, convulsions Chronic: psychological disturbances, mania with hallucinations	Concentrated acid gas
Carbon monoxide	Acute: headache, dizziness, weakness, vomiting, collapse, death Chronic: low-level chronic effects not established	Coal-lockhopper vent gas Raw gas from gasifier
Carbonyl sulfide	Little data on human toxicity	Concentrated acid gas
Hydrogen sulfide	Acute: collapse, coma, and death may occur within a few seconds. Insidious, may not be detected by smell Chronic: possible cocarcinogen	Coal-lockhopper vent gas Raw gas from gasifier Concentrated acid gas Catalyst regeneration off-gas
Hydrogen cyanide	Acute: headache, vertigo, nausea, paralysis, coma, convulsions, death Chronic: fatigue, weakness	Concentrated acid gas Coal-lockhopper vent gas
Mineral dust and ash	Chronic: possible vehicle for polycyclic aromatic hydrocarbons and cocarcinogens	Ash or slag
Nickel carbonyl	Acute: highly toxic, irritation, lung edema Chronic: carcinogen to lungs and sinuses	Catalyst regeneration off-gas
Trace elements: arsenic, beryllium, cadmium, lead, manganese, mercury, selenium, vanadium	(Complex)	Bottom ash Fly ash Gasifier ash Solid waste disposal
Sulfur oxides	Acute: intense irritation of respiratory tract Chronic: possible cocarcinogen	Combustion flue gases
Organic		
Aliphatic hydrocarbons	Most not toxic. N-Dodecane potentiates skin tumors	Evaporative emissions from product storage
Aromatic amines	Acute: cyanosis, methemoglobinemia, vertigo, headache, confusion Chronic: anemia, skin lesions (aniline) Benzidine and beta-naphthylamine are powerful carcinogens	Coal-lockhopper vent gas Gas liquor
Single-ring aromatics	Acute: irritation, vomiting, convulsions Chronic: bone-marrow depression, aplasia	Coal-lockhopper vent gas Gas liquor
Aromatic nitrogen heterocyclics	Acute: skin and lung irritants Chronic: possible cocarcinogens	Gas liquor Coal-lockhopper vent gas
Phenols	Chronic: possible carcinogens, skin and lungs	Gas liquor
Polycyclic aromatic hydrocarbons (PAH)	Chronic: skin carcinogens, possible respiratory carcinogens	Gas liquor Coal-lockhopper vent gas Raw gas

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment. Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

nature of the direct process stream (which contains entrained solids); and fewer dangerous aromatic compounds, including polynuclear aromatics and aromatic amines, than in direct process streams. Lurgi gasifiers, however, produce a wider range of organic compounds than the higher temperature gasifiers and as a result are more comparable in health risk to direct processes.

In sum, however, the indirect processes appear to have a lower *potential* for occupational health and safety problems than the direct processes. In actual practice other factors—such as differences in the selection of control equipment and in plant design, maintenance procedures, and worker training—conceivably could outweigh these differences. In fact, developers of liquefaction processes appear to be aware of the potential hazards and are taking preventive action such as providing special clothing and providing frequent medical checkups. Nevertheless, the occupational health risk associated with synthetic fuel plants must be considered a major concern.

Ground and Surface Water Contamination.—A portion of the solid waste produced by liquefaction plants is ash-bottoms, fly ash, and scrubber sludge from the coal-fired boilers—materials that are routinely handled in all coal-fired powerplants today. Much of the waste, however, is ash or slag from the gasifiers producing synthesis gas or hydrogen and chars or "bottoms" from the direct processes (although much of the latter material is expected to be recycled to the gasifiers). As noted previously, this material is produced in a reducing atmosphere and thus contains organic compounds as well as trace elements whose solubility may be different from that produced in the boiler.

Other solid wastes that may create disposal problems more severe than those of powerplant waste include spent catalysts and sludges from water treatment. Total solid wastes from a 50,000 bbl/d plant range from 1,800 to 5,000 or more tons per day.[65] At these rates, a 2 MMB/D industry would have to dispose of between 26 million and 72 million tons of wastes per year. The major concern from these materials is that water percolating through landfill disposal areas may leach the toxic organic compounds and trace elements out of the wastes and into the ground water. Currently, the extent of this risk is uncertain, although tests of EDS[66] and SRC-II[67] liquefaction reactor wastes and gasifier ash from several gasifiers[68] yielded leachates that would not have been rated as "hazardous" under Resources Conservation and Recovery Act criteria.*

One major problem with permanent landfill disposal, however, is that damage to ground water may occur at any future time when the landfill liner may be breached—many of the toxic materials in the wastes are either not degradable or will degrade very slowly, and may last longer than the design life of the liner.

Liquid effluent streams from liquefaction plants also pose potential water pollution problems. Although there are a number of wastewater sources that are essentially conventional in character—cooling tower and boiler blowdown, coal storage pile runoff, etc.—the major effluent streams, from the scrubbing of the gases from the gasifiers and from the water separation streams in the direct processes, contain a variety of organics and trace metals that will pose difficult removal problems. The direct processes are expected to have the dirtiest effluent streams, the indirect systems based on Lurgi gasifiers will also pose some problems because of their high production of organics, and the systems based on high-temperature gasifiers should have only moderate treatment requirements.[69]

Although total recycle of water is theoretically possible, in practice this is unlikely and "zero discharge" will only be achieved by using evaporation ponds. Aside from the obvious danger of breakdown of the pond liner and subsequent ground water contamination (or overflows from flooding), evaporation ponds may pose environmental problems through the formation of toxic gases or evaporation of volatile liquids. The complex mixture of active compounds in such a pond creates a particular hazard of unforeseen reactions occurring.

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[65] Chartock, et al., op. cit.

[66] R. C. Green, "Environmental Controls for the Exxon Donor Solvent Liquefaction Process," *Second DOE Environmental Control Symposium*, Reston, Va., Mar. 19, 1981.

[67] Supra 59.

[68] *Inside EPA*, Sept. 26, 1980. As reported, researchers from TRW and Radian Corps. have tested ash from Lurgi, Wellman-Galusha, and Texaco gasifiers.

*Wastes are rated as "hazardous" and will require more secure (and more expensive) disposal if concentrations of pollutants in the leachates are greater than 100 times the drinking water standard.

[69] H. Gold, et al., "Fuel Conversion and Its Environmental Effects," *Chemical Engineering Progress*, August 1979.

Although the use of ponds to achieve zero discharge is practical in the West because of the low rainfall and rapid evaporation rates, zero discharge may be impractical at eastern sites without artificial evaporation, which is expensive and energy-intensive. Consequently, it appears probable that continuous or intermittent effluent discharges will occur at eastern plants, with added risks from control system failures as one result.

Environmental Management

The likelihood of these very serious *potential* environmental and health risks turning into *actual impacts* depends on a variety of factors, and particularly on the effectiveness and reliability of the proposed environmental controls for the plants, the effectiveness of environmental regulations and scientists' ability to detect damages and ascertain their cause.

In general, synfuels promoters appear to be confident that the control systems proposed for their processes will work effectively and reliably. They tend to view synfuels processes as variations of current chemical and refinery operations, albeit variations that will require careful design and handling. Consequently, the environmental controls planned for synthetic fuels plants are largely based on present engineering practices in the petroleum refining, petrochemical, coal-tar processing, and power generation industries.

There are reasons to be concerned about control system effectiveness and reliability, however, especially for the first generation of commercial plants. First, few of the wastewater effluents from either direct or indirect processes have been sent through a complete environmental control system such as those designed for commercial units. Process waste streams from several U.S. pilot plants have been subjected only to laboratory and bench-scale cleanup tests or else have been combined with waste streams from neighboring refineries and treated, with a poorly understood level of success, in the refinery control systems.

Second, scaling up from small-scale operations is particularly difficult for the direct processes, because of the entrainment of solids in the liquid process streams. Engineering theory for the scale up of solids and mixed solids/liquids processes is not well advanced. For the most part, the problem of handling liquid streams containing large amounts of entrained solids under high-temperature and pressure conditions is outside of current industrial experience.

Third, currently available refinery and petrochemical controls are not designed to capture the full range of pollutants that will be present in synfuels process and waste streams. Several of the trace elements as well as the polycyclic aromatic hydrocarbons (PAHs) are included in this group, although techniques such as hydrocracking are expected to help eliminate PAHs when they appear in process streams. (As noted previously, problems with the trace organics generally are focused on the direct and on low-temperature indirect processes, because high-temperature gasifiers should effectively destroy most of these compounds.)

Fourth, in some cases, compounds that generally are readily controlled when separately encountered appear in synfuels process and waste streams in combinations that complicate control. For example, current processes for removing hydrogen sulfide, carbonyl sulfide, and combustibles tend to work against each other when these compounds appear in the same gas stream,[70] as they do in synfuels plants. Also, the high level of toxics that appear in the waste streams may create reliability problems for the biological control systems.

Fifth, as noted earlier, the high pressures, multiplicity of valves and gaskets, and (for the direct processes) the erosive process streams appear to create high risks of fugitive emissions. Plans for control of these emissions generally depend on "directed maintenance" programs that stress frequent monitoring and inspection of vulnerable components. Although it appears reasonable to expect that a directed maintenance program can significantly reduce fugitive emissions, rigorous specifications for such a program have not been published,[71] and some doubts have been raised about the adequacy of proposed monitoring for pioneer plants.

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[70] Congressional Research Service, *Synfuels From Coal and the National Synfuels Production Program: Technical, Environmental, and Economic Aspects,* December 1980 (Committee Print 11-74 No. 97-3, January 1981, U.S. Congress).

[71] U.S. Department of Energy, *Final Environmental Impact Statement: Solvent Refined Coal-II Demonstration Project,* Fort Martin, Monongalia County, W. Va., 2 vols., 1981.

The significance of these technological concerns is uncertain. As noted previously, industry representatives generally have dismissed the concerns as unimportant, at least with regard to the extent to which pollution control needs might be compromised. Government researchers at EPA and DOE[72] have expressed some important reservations, however. On the one hand, they are confident that each of the synfuels waste streams is amenable to control, usually with approaches that are not far different from existing approaches to control of refinery and chemical process wastes. On the other hand, they have reservations about whether or not the industry's control program, as it is currently constituted, will achieve the high levels of control possible. Potential problem areas (some of which are related) include wastewater treatment,[73] control system reliability, and pollution control during process upsets.

Virtually all of the Government researchers OTA contacted were concerned that the industry programs were not addressing currently unregulated pollutants but instead were focusing almost exclusively on meeting immediate regulatory requirements. Several expressed special concern about the failure of some developers to exploit all available opportunities to test integrated control systems; they expected these integrated systems to behave differently from the way the individual devices behave in tests.

The above concerns, if well founded, imply that environmental control problems could have serious impacts on the operational schedules of the first generation of commercial plants. These impacts could range from extentions in the normal plant shakedown periods to extensive delays for redesign and retrofit of pollution controls.[74] Because of the large capital costs of the plants, there will likely be severe pressure on regulators to minimize delays and allow full-scale production to proceed. The outcome of any future conflicts between regulatory requirements and plant schedules will depend strongly on the public pressures exerted on the industry and Federal and State Governments.

There are reasons to believe that a great deal of public interest will be focused on the synfuels industry and its potential effects. For one, when plant upsets do occur, the results can be visually spectacular—for example, purging an SRC-II reactor vessel and flaring its contents can produce a flame up to 100 ft wide and 600 ft long.[75] It also seems likely that odor problems will accompany these first plants, and in fact the sensitivity of human smell may render it impossible to ever completely eliminate this problem. Malodorous compounds such as hydrogen sulfide, phenols, organic nitrogen compounds, mercaptans, and other substances that are present in the process and waste streams can be perceived at very low concentrations, sometimes below 1 part per billion.[76]

In addition, the presence of highly carcinogenic materials in the process and waste streams appears likely to sensitize the public to any problems with these plants. This combination of potential hazards and perceptual problems, coupled with the industry strategy of locating at least some of these plants quite close to populated areas (e.g., SRC-II near Morgantown, W. Va., now canceled, and the Tri-State Synthetic Fuels Project near Henderson, Ky.), appears likely to guarantee lively public interest.

The nature of the industry's response to unexpected environmental problems as well as its general environmental performance also will depend on the degree of regulatory surveillance and control exerted by Federal and State environmental agencies. Although the degree of surveillance and control will in turn depend largely on the environmental philosophy of the Federal and State Governments at various stages in the lifetime of the industry—a factor that is unpredictable—it will also depend on the legal framework of environmental regulations, the scientific groundwork that is now being laid by the environmental agencies, and the nature of the scientific problems facing the regulatory system.

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[72] Personal communications with headquarters and field personnel, EPA and DOE.

[73] The draft of EPA's Pollution Control Guidance Document on indirect liquefaction also expressed strong concerns about wastewater treatment. *Inside EPA*, Sept. 12, 1980, "Indirect Liquids Draft Sees Zero Wastewater Discharge, Laments Data Gap."

[74] Some of the architectural and engineering firms submitting synfuels plant designs have incorporated certain control system flexibilities as well as extra physical space in their control systems designs. These features presumably would reduce schedule problems. Frederick Witmer, Department of Energy, Washington, D.C., personal communication.

[75] Supra 59.

[76] Supra 58.

Existing Federal environmental legislation gives the Occupational Safety and Health Administration (OSHA) and EPA a powerful set of tools for dealing with the potential impacts of synfuels development. OSHA has the power to set occupational exposure standards and define safety procedures for all identified hazardous chemicals in the workplace environment. EPA has a wide variety of legal powers to deal with synfuels impacts, including:

- setting National Emission Standards for Hazardous Air Pollutants (NESHAPs) under the Clean Air Act;
- setting New Source Performance Standards, also under the Clean Air Act;
- setting effluent standards for toxic pollutants (which, when ingested, cause "death, disease, cancer, genetic mutations, physiological malfunctions or physical deformations") under the Clean Water Act;
- setting water quality standards, also under the Clean Water Act;
- defining acceptable disposal methods for hazardous wastes under the Resource Conservation and Recovery Act;
- defining underground injection guidelines under the Safe Drinking Water Act; and
- a variety of other powers under the mentioned acts and several others.[77]

The regulatory machinery gives the Federal environmental agencies a strong *potential* means of controlling synfuels plants' hazardous emissions and effluents. In general, however, the machinery is immature. Because there are no operating commercial-scale synthetic fuels plants in the United States, EPA has not had the opportunity to collect the data necessary to set any technology-specific emission and effluent limitations for synfuels plants. Aside from this inevitable problem, the environmental agencies have not fully utilized some of their existing opportunities for environmental protection. For example, EPA has allowed its authority to define standards for hazardous air pollutants to go virtually unused. In addition, in some areas, such as setting effluent guidelines and New Source Performance Standards for air emissions, EPA has a substantial backlog of existing industries yet to be dealt with.

The environmental research programs conducted by various Federal agencies will lay the groundwork for EPA's and OSHA's regulation of the synfuels industry. The key programs are those of EPA and OSHA themselves and those of DOE. DOE's programs appear likely to be essentially eliminated if current plans to dismantle DOE are successful. EPA and OSHA research budgets have both been reduced. In particular, EPA has essentially eliminated research activities aimed at developing control systems for synfuels waste streams, on the basis that such development is the appropriate responsibility of industry. As mentioned before, Federal researchers familiar with the industry's current environmental research programs perceive that the industry has little interest in developing control measures for potential impacts that are not currently regulated, and they believe that industry is unlikely to expand its programs to compensate for EPA's reductions.[78]

With or without budget cuts, EPA and OSHA face substantial scientific problems in setting appropriate standards for hazardous materials from synfuels technologies. Probably the worst of these problems is that current air pollution and occupational exposure regulations focus on a relatively small number of compounds and treat each one individually or in well-defined groups, whereas synfuels plants may emit dozens or even hundreds of dangerous compounds with an extremely wide range of toxicity (i.e., the threshhold of harm may range from a few parts per billion to several parts per thousand or higher) and a variety of effects.

The problem is further complicated by the expected wide variations in the amounts and types of pollutants produced. The synfuels waste streams are dependent on the type of technology, the control systems used, the product mix chosen by the operator (which determines the operating conditions), and the coal characteristics. The implication is that uniform emission and worker exposure standards, such as a "pounds per hour" emission limit on total fugitive HC emissions or a "milligrams per cubic meter" limit on HC exposures, are unlikely to be practical because they would have to be extraordinarily stringent to provide adequate protection against all components of the emission streams. Consequently, EPA and OSHA may not be able to avoid the extremely difficult task of setting multiple separate standards for toxic substances.

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[77] See table 4-1, *Synthetic Fuels and the Environment: An Environmental and Regulatory Impacts Analysis*, Office of Technology Impacts, U.S. Department of Energy, DOE/EV-0087, June 1980. Also, see ch. 5, *The Impacts of Synthetic Fuels Development*, D. C. Masselli, and N. L. Dean, Jr., National Wildlife Federation, September 1981.

[78] Supra 72.

The regulatory problem represented by the toxic discharges is compounded by difficulties in detecting damages and tracing their cause. Because low-level fugitive emissions from process streams and discharges or leaks from waste disposal operations probably are inevitable, regulatory requirements on the stringency of mitigation measures will depend on our knowledge of the effects of low-level chronic exposures to the chemical components of these effluents. Aside from the problems of monitoring for the actual presence of pollution, problems may arise both from the long lag times associated with some critical potential damages (e.g., 5 to 10 years for some skin cancers, longer for many soft-tissue cancers) and from the complex mixture of pollutants that would be present in any emission.

Transport and Use

As synthetic liquids are distributed and used throughout the economy, careful control of exposure to hazardous constituents becomes less and less feasible. This is especially true for liquid fuels because of the multitude of small users and the general lack of careful handling that is endemic to the petroleum distribution system. Consequently, the toxicity of synfuels final products may be critical to the environmental acceptability of the entire synfuel "fuel cycle."

The pathways of exposure to hazardous substances associated with synfuels distribution and use include accidental spills and fugitive emissions from pipelines, trucks, and other transport modes and storage tanks; skin contact and fume inhalation by motorists and distributors; and public worker exposure to waste products associated with combustion (including direct emissions and collected wastes from control systems).

Evaluation of the relative danger of these exposure pathways and comparisons of synfuels to their petroleum analogs are extremely difficult at this time. Most environmental and health effects data on synfuels apply to process intermediates—"syncrudes"—rather than finished fuels. Combustion tests have generally been limited to fuel oils in boilers rather than gasolines in automobiles.[79] The tests that have been conducted focus more on general combustion characteristics than on emissions, and those emission characterizations that have been done measure mainly particulates and SO_x and NO_x rather than the more dangerous organics.[80] Adding to the difficulty of determining the relative dangers of synfuels use is a series of surprising gaps in health effects data on analogous petroleum products. Apparently, many of these widely distributed products are assumed to be benign, and monitoring of their effects has been limited.[81]

Table 79 presents a summary of the known differences in chemical, combustion, and health effects characteristics of various synfuels products and their petroleum analogs. The major characteristics of coal-derived liquid fuels are:

- The major concern about synthetic fuels products is their potential to cause cancer, mutations, or birth defects in exposed persons or wildlife. (Petroleum-based products also are hazardous, but usually to a lesser extent than their synfuels counterparts.)[82] In general, the heavier (high boiling point) liquids—especially heavy fuel oils—are the most dangerous, whereas most of the lighter products are expected to be relatively free of these effects. This distribution of effects may be considered fortunate because the lighter

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[79] M. Ghassemi and R. Iyer, *Environmental Aspects of Synfuel Utilization,* U.S. Environmental Protection Agency report EPA-600/7-81-025, March 1981.

[80] Ibid.

[81] Ibid.

[82] Ibid.

Table 79.—Reported Known Differences in Chemical, Combustion, and Health Effects Characteristics of Synfuels Products and Their Petroleum Analogs

Product	Chemical characteristics	Combustion characteristics	Health effects characteristics
Shale oil			
Crude	Higher aromatics, FBN, As, Hg, Mn	Higher emissions of NO_x, particulate and (possibly) certain trace elements	More mutagenic, tumorigenic, cytotoxic
Gasoline	Higher aromatics	Slightly higher NO_x and smoke emissions	—
Jet fuels	Higher aromatics	Slightly higher NO_x and smoke emissions	Eye/skin irritation, skin sensitization same as for petroleum fuel
DFM	Higher aromatics	Slightly higher NO_x and smoke emissions	Eye/skin irritation, skin sensitization same as for petroleum fuel
Residuals	Higher aromatics	—	—
Direct liquefaction			
Syncrude (H-Coal, SRC II, EDS)	Higher aromatics and nitrogen	—	—
SRC II fuel oil	Higher aromatics and nitrogen	Higher NO_x emissions	Middle distillates: nonmutagenic; cytotoxicity similar to but toxicity greater than No. 2 diesel fuel; burns skin. Heavy distillate: considerable skin carcinogenicity, cytotoxicity, mutagenicity, and cell transformation
H-Coal fuel oil	Higher nitrogen content	Higher NO_x emissions	Severely hydrotreated: nonmutagenic, nontumorigenic; low cytotoxicity
EDS fuel oil	—	Higher NO_x emissions	—
SRC II naphtha	Higher nitrogen, aromatics	—	Nonmutagenic, extremely low tumorigenicity cytotoxicity and fetotoxicity
H-Coal naphtha	Higher nitrogen, aromatics	—	Nonmutagenic
EDS naphtha	Higher nitrogen, aromatics	—	—
SRC II gasoline	Higher aromatics	—	—
H-Coal gasoline	Higher aromatics	—	—
EDS gasoline	Higher aromatics	—	—
Indirect liquefaction			
FT gasoline	Lower aromatics; N and S nil	—	Noncarcinogenic
FT byproduct chemical	—	N/A	—
Mobil-M gasoline	(Gross characteristics similar to petroleum gasoline)	—	—
Methanol	—	Higher aldehyde emissions	Affects optic nerve
Gasification			
SNG	Traces of metal carbonyls and higher CO	—	—
Low/medium-Btu gas	(Composition varies with coal type and gasifier design/operation)	(Emissions of a wide range of trace and minor elements and heterocyclic organics)	Nonmutagenic, moderately cytotoxic
Gasifier tars, oils, phenols	(Composition varies with coal and gasifier types; highly aromatic materials)	—	—

SOURCE: M. Ghassemi and R. Iyer, *Environmental Aspects of Synfuel Utilization*, EPA-600/7-81-025, March 1981.

products—such as gasoline—are more likely to be widely distributed.

- Products from direct liquefaction processes appear more likely to be cancer hazards than do indirect process products, because of the higher levels of dangerous organic compounds produced in the direct processes.
- Coal-derived methanol fuel appears to be similar to the methanol currently being used, although there are potentials for contamination that must be carefully examined. Methanol is rated as a "moderate hazard" ("may involve both irreversible and reversible changes not severe enough to cause death or permanent injury")[83] under chronic —long-term, low-level—exposure, although the effects of multi-year exposures to very low levels (as might occur to the public with widespread use as a fuel) are not known. Methanol has been assigned a hazard rating for *acute* exposures similar to that for gasoline,[84] but no comparison can be made for chronic exposures because data for gasoline exposure is inadequate.[85] [86] In automobiles, methanol use increases emissions of formaldehyde sufficiently to cause concern, but lowers emissions of nitrogen oxides and polynuclear aromatics.[87] Depending on the potential health effects of low levels of formaldehyde, which are not now sufficiently understood, and the emission controls on automobiles, methanol use in automobiles conceivably may provide a significant net pollution benefit to areas suffering from auto-related air pollution problems.
- Many of the dangerous organics that are the source of carcinogenic/mutagenic/teratogenic properties in synfuels should be controllable by appropriate hydrotreating. Tradeoffs between environmental/health concerns and hydrotreating cost, energy consumption, and effects on other product characteristics currently are not known.

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[83] N. I. Sax, *Dangerous Properties of Industrial Materials, Fourth Edition,* Van Nostrand Reinhold Co., 1975.

[84] Ibid.

[85] Ibid.

[86] Ghassemi and Iyer, op. cit.

[87] *Energy From Biological Processes,* op. cit.

OIL SHALE

Production and use of synthetic oil from shale raises many of the same concerns about limited water resources, toxic waste streams and massive population impacts as coal-derived liquid fuels, but there are sufficient differences to demand separate analysis and discussion. OTA has recently published an extensive evaluation of oil shale;[88] the discussion here primarily summarizes the key environmental findings of that study.

U.S. deposits of high-quality oil shale (greater than 25 gal of oil yield per ton) generally are concentrated in the Green River formation in northwestern Colorado (Piceance Basin) and northeastern Utah (Uinta Basin). The geographic concentration of these economically viable reserves to an arid, sparsely populated area with complex terrain and relatively pristine air quality, and the impossibility of transporting the shale (because of its extremely low energy density) lead to a potential concentration of impacts that is (at least in theory) easier to avoid with coal-derived synfuels. Thus, compliance with prevention of significant deterioration regulations for SO_2 and particulates may constrain total oil shale development to a million barrels per day or less unless current standards are changed or better control technologies are developed.

Also, the lack of existing socioeconomic infrastructure implies that environmental impacts associated with general development pressures could be significant without massive mitigation programs. Although coal development shares these concerns (especially in the West) and has water and labor requirements as well as air emissions that are not dissimilar on a per-plant basis, it is unlikely to be necessary to concentrate coal development to the same extent as with oil shale. Thus, coal development should have fewer severe physical limitations on its total level of development.

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[88] *An Assessment of Oil Shale Technologies,* op. cit.

The geographic concentration of oil shale development should not automatically be interpreted as environmentally inferior to a more dispersed pattern of development, however. Although impacts will certainly be more severe in the developed areas as a result of this concentration, these impacts must be balanced against the smaller area affected, the resulting pressure on the developers to improve environmental controls to allow higher levels of development, and the possibility of being able to focus a major monitoring and enforcement effort on this development. Also, the major oil shale areas generally are not near large population centers, whereas several proposed coal conversion plants are within a few miles of such centers and may consequently pose higher risks to the public.

The volume of the material processed and discarded by an oil shale plant is a significant factor in comparing oil shale with coal-derived fuels. A 50,000 bbl/d oil shale plant using aboveground retorting (AGR) requires about 30 million tons per year of raw shale* versus about 6 million to 18 million tons of coal (the higher values apply only to low-quality lignites converted in a relatively inefficient process) for a similarly sized coal liquefaction plant. A modified in-situ (MIS) plant requires about the same tonnage of feedstock as does the coal plant. Consequently, although the underground mining of shale thus far has had a much better worker safety record than coal mining, underground mining of coal may be safer than shale mining for an AGR plant on a "fuel output" basis, especially when full-scale shale mining begins. Mining for an MIS plant, on the other hand, will be safer than that for the coal plant unless previous shale experience proves to be misleading.

The very large amount of spent shale represents a difficult disposal problem. An AGR plant must dispose of about 27 million tons/yr of spent shale, at least five times as much solid waste as that produced by a similarly sized coal synfuels plant (MIS plants may dispose of about 6 million tons/yr of spent shale, one to three times the disposal requirements of a coal plant). At this rate, a 1 MMB/D industry using AGRs will have to dispose of approximately 10 billion cubic feet of compacted shale each year.

This material cannot be fully returned to the mines because it has expanded during processing, and it is a difficult material to stabilize and secure from leaching dangerous compounds—cadmium, arsenic, and lead, as well as organics from some retorts (for example TOSCO II and Parajo Indirect)—into surface and ground waters. It also may cause a serious fugitive dust problem, especially with processes like TOSCO II that produce a very fine waste. Even with secure disposal, it will fill scenic canyons and represents an esthetic and ecosystem loss. Current research on small plots indicates that short-term (a few decades) stability of spent shale piles appears likely if sufficient topsoil is applied, but the long-term stability and the self-sustaining character of the vegetation is unknown. For these reasons, solid waste disposal may be oil shale's major environmental concern.

As with coal liquefaction processes, the "reducing environment" in the retorts produces both reduced sulfur compounds and dangerous organics that represent a potential occupational hazard for workers from fugitive emissions and fuel handling. Crude shale oil appears to be more mutagenic, carcinogenic, and teratogenic than natural crude.

On the other hand, the refined products are less likely to be significantly different in effect from their counterparts produced from natural crude, and shale syncrude is less carcinogenic or mutagenic than syncrudes from direct coal liquefaction. Although comparisons of relative risk must necessarily be tentative at this early stage of development, it appears that the risks from these toxic substances—excluding problems with spent shale—probably are somewhat comparable to those of the cleanest coal-based liquefaction processes (indirect liquefaction with high-temperature gasifiers).

Other oil shale environmental effects of particular concern include:

- The mining of oil shale generates large amounts of silica dust that is implicated in various disabling lung diseases in miners.

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*Assuming 25 gal of oil per ton of shale.

- Aside from the reduced sulfur compounds and organics, the crude shale oil contains relatively high levels of arsenic, and somewhat higher levels of fuel bound nitrogen than most natural crude does. These pollutants as well as the organics can be reduced in the refining operation.
- In-situ production leaves large quantities of spent shale underground and thus creates a substantial potential for leaching out toxic materials into valuable aquifers. Control of such leaching has not been demonstrated.
- Although oil shale developers are proposing to use zero discharge of point-source water effluents, it may be desirable in the future to treat water and discharge it. The state of water pollution control in oil shale development is essentially the same as in coal-derived synfuels, however. Many of the controls proposed have not been tested with actual oil shale wastewaters, and none have been tested in complete wastewater control systems.
- MIS production—whereby a moderate amount of mining is done to provide space with which to blast the shale into rubble and then retort it underground—may present a special occupational hazard to workers from explosions, fire, and toxic gases as well as a potential danger to the public if toxic fumes escape from the mine to the surface.

To summarize, the environmental concerns of oil shale production appear to be quite similar to those of coal-based synfuels production, but with two important differences. First, the geographic concentration of oil shale production will tend to concentrate and intensify its environmental and socioeconomic impacts to a greater extent than is likely to be experienced by coal development. Second, the problems of disposing of the huge quantities of spent shale associated with the AGR system appear to be substantially greater than those of coal wastes.

BIOMASS FUELS

Production of liquid fuels from biomass will have substantially different impacts from those of coal liquefaction and oil shale production. These are described in detail in OTA's *Energy From Biological Processes*[89] and summarized briefly here.

The liquid fuel that appears to have the most potential for large-scale production is methanol produced from wood, perennial grasses and legumes, and crop residues. Ethanol from grains has been vigorously promoted in the United States, but appears likely to be limited by problems of food/fuel competition to moderate production levels (a few billion gallons per year).

Obtaining the Resource

Environmental concerns associated with alcohol fuel production focus on feedstock acquisition to a greater extent than with coal liquefaction. All of the credible alcohol fuel cycles require various degrees of ecological alteration, replacement, or disruption on vast land areas. Taking into account the expenditure of premium fuels needed to obtain and convert the biomass into usable fuels, replacing about 10 billion gal/yr of gasoline with biomass substitutes would require adding intensive cropping to a minimum of about 25 million acres with a combination of sugar/starch crops (for ethanol) and grasses (for methanol).

If this savings were attempted strictly by the use of ethanol made from corn, the land requirement probably would be at least 40 million acres. If methanol from wood were the major source, much of the gasoline displacement theoretically could be obtained by collecting the logging residues that are now left in the forest or burned. To replace 10 billion gal over and above the amount available from residues would involve increasing the scale and intensity of management (more acreage under intensive management, shorter times between thinnings, more complete removal of biomass, more conversion of low-quality stands) on upwards of 50 million acres of commercial forest. It might involve an increased harvest of forestland with lower productive potential—so-called "marginal lands"—and it will almost certainly mean that lands not now subject to logging will be logged. Despite these difficulties, however, wood is the most likely source of large-scale biomass production.

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[89] *Energy From Biological Processes*, op. cit.

If handled with care, a "wood-for-methanol" strategy could have a number of benefits. These include upgrading of poorly managed forests, better forest fire and pest control through slash removal, and reduced pressure on the few remaining unprotected stands of scenic, old-growth timber because of the added yields of high-quality timber that are expected in the long run from increased management.

Nevertheless, there is substantial potential for damage to the forests if they are mismanaged. High rates of biomass removal coupled with short rotations could cause a depletion of nutrients and organic matter from the more vulnerable forest soils. The impacts of poor logging practices—erosion, degraded water quality, esthetic damage, and damage to valuable ecosystems—may be aggravated by the lessening of recovery time (because of the shorter rotations) and any lingering effects of soil depletion on the forests' ability to rebound. The intensified management may further degrade ecological values if it incorporates widespread use of mechanical and chemical brush controls, very large area clearcuts and elimination of "undesirable" tree species, and if it neglects to spare large pockets of forest to maintain diversity.

Finally, the incentive to "mine" wood from marginal lands with nutrient deficiencies, thin soils, and poor climatic conditions risks the destruction of forests that, although "poor" from the standpoint of commercial productivity, are rich in esthetic, recreational, and ecological values. Because the economic and regulatory incentives for good management are powerful in some circumstances but weak in others, a strong increase in wood energy use is likely to yield a very mixed pattern of benefits and damages unless the existing incentives are strengthened.

The potential effects of obtaining other feedstocks for methanol or ethanol production may also be significant. Obtaining crop residues, for example, must be handled with extreme care to avoid removing those residues that are critical to soil erosion protection. Large-scale production of corn or other grains for ethanol is likely to occur on land that is, on the average, 20 percent more erosive than present cropland. Aside from creating substantial increases in erosion, corn production will require large amounts of agricultural chemicals, which along with sediment from erosion can pollute the water, and will displace present ecosystems.

Equivalent production levels of perennial grasses and legumes, on the other hand, could be relatively benign because of these crops' resistance to erosion as well as their potential to be obtained by improving the productivity of present grasslands rather than displacing other ecosystems. Although large quantities of agricultural chemicals would be used, the potential for damage will be reduced by the low levels of runoff from grasslands.

Conversion

Production of alcohol fuels will pose a variety of air and water pollution problems. Methanol synthesis plants, for example, are small indirect liquefaction plants that may have problems similar to those of coal plants discussed previously. The gasification process will generate a variety of toxic compounds including hydrogen sulfide and cyanide, carbonyl sulfide, a multitude of oxygenated organic compounds (organic acids, aldehydes, ketones, etc.), phenols, and particulate matter. As with coal plants, raw gas leakage or improper handling of tars and oils would pose a significant hazard to plant personnel, and good plant housekeeping will be essential. Because of low levels of sulfur and other pollutants in biomass, however, these problems may be somewhat less severe than in an equivalent-size coal plant.

Ethanol distilleries use substantial amounts of fuel—and therefore can create air pollution problems. An efficient 50-million-gal/yr distillery will consume slightly more fuel than a 30-Mw powerplant. There are no Federal emissions standards for these plants, and the prevailing local standards may be weak in some cases, especially for small onfarm operations.

The plants also produce large amounts of sludge wastes, called stillage, that are high in biological and chemical oxygen demand and must be kept out of surface waters. Although the stillage from grains is a valuable animal feed product and will presumably be recovered without the need for any further incentives, the stillage from sugar crops is less valuable and will require strict regulation to avoid damage to aquatic ecosystems. EPA has had a history of pollution control problems with rum and other distilleries, and ethanol plants will be similar to these.

APPENDIX 10A.—DETAILED DESCRIPTIONS OF WASTE STREAMS, RESIDUALS OF CONCERN, AND PROPOSED CONTROL SYSTEMS FOR GENERIC INDIRECT AND DIRECT COAL LIQUEFACTION SYSTEMS

Table 10A-1.—Gaseous Emissions and Controls (indirect liquefaction)

Gaseous stream	Source	Stream components of concern	Controls	Comments
Fugitive emissions				
Vent gases				
Coal-lockhopper vent gas	Coal gasification	Carbon monoxide, hydrogen sulfide, tars, oils, naphtha, cyanide, carbon disulfide	Compression and recycle of pressurization gas, incineration of waste gas	—
Ash-lockhopper vent gas	Coal gasification	Particulates, trace elements	Scrubber	The need for and the effectiveness of incineration/particulate control have not been defined
Concentrated acid gas	Gas purification	Hydrogen sulfide, carbonyl sulfide, carbon disulfide, hydrogen cyanide, carbon monoxide, carbon dioxide, light hydrocarbons, mercaptans	Stretford or ADIP/Claus processes followed by a sulfur recovery tail gas process, e.g., Beavon, and incineration of the Beavon off-gas in a boiler	The acid gases will be concentrated by the gas purification process. The control choice is dependent on the sulfur content of the gases; a combination of Stretford and ADIP/Claus may have the lowest overall costs.
Off-gases from catalyst regeneration	Catalytic synthesis	Nickel and other metal carbonyls, carbon monoxide, sulfur compounds, organics	Incineration in a flare, incinerator, or controlled combustion	Other control technology requirements not established
Evaporative emissions from stored products	Product storage	Aromatic hydrocarbons, C_5-C_{12} aliphatic hydrocarbons, ammonia	Vapor recovery systems, use of floating roof storage tanks, conservation vents. Incinerate	Control technologies used in petroleum refinery and other industries should be applicable to Lurgi plants; standards promulgated for the petroleum refining industry would probably be extended to cover the synthetic fuel industry.
Auxiliary plant emissions				
Flue gases	Power/steam generation	Sulfur and nitrogen oxides, particulates trace elements, coal fines	Electrostatic precipitators, fabric filters, flue-gas desulfurization systems, combustion modification	Controls applicable to utility and industrial boilers would generally be applicable. Established emissions regulations would cover boilers at Lurgi plants
Cooling-tower drift and evaporation	Power/steam generation, process cooling	Ammonia, sodium, calcium, sulfides/sulfates, chlorine, phenols, fluorine, trace elements, water treatment chemicals	Proper design and siting can mitigate impacts	Recycled process water is used for cooling-tower makeup. If cooling-tower drift becomes a problem then the recycled water will receive additional treatment or makeup water will come from another source.
Treated waste gases	Gaseous emission controls (e.g., sulfur recovery	Hydrogen sulfide, carbonyl sulfide, carbon disulfide, hydrogen cyanide, carbon monoxide, carbon dioxide, light hydrocarbons	Essentially the same as for the concentrated acid gas	—

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Table 10A-2.—Liquid Waste Stream Sources, Components, and Controls (indirect liquefaction)

Liquid waste stream	Source	Stream components of concern	Controls	Comments
Ash quench water	Gasification	Dissolved and suspended solids, trace elements, sulfides, thiocyanate, ammonia, dissolved organics, phenols, cyanides	Gravity settling of solids; the overflow from the settling basin is recycled back to the ash quenching operation	See table 10A-3, Solid Waste Streams, for final disposition of ash solids. Capabilities of technology in terms of clarified ash slurry water not known
Gas liquor	Gas purification	Sulfides, thiocyanate, ammonia, cyanides, mono- and polycyclic organics, trace metals, mercaptans	Lurgi tar/oil separator	Capabilities of tar/oil separation, Phenosolvan, and ammonia recovery well established in terms of removal of major constituents. Capabilities for removal of minor constituents not established. Limited cost data available on processes.
			Phenosolvan process	Removes dissolved phenols from water
			Phosam W or Chemi-Linz	Removes dissolved ammonia, produces saleable anhydrous ammonia.
			Bio-oxidation and reverse osmosis	Removes dissolved organics and inorganics.
Boiler blowdown	Power/steam generation	Dissolved and suspended solids	Use as cooling-tower makeup or as ash quench water makeup	Impacts on the quench system and subsequent treatment of clarified water not established.
Spent reagents and sorbents	Gaseous emission controls, wastewater treatment	Sulfides, sulfates, trace elements, dissolved and suspended solids, ammonia, phenols, tar oils, hydrogen sulfide, carbon dioxide	Recovery of reagents from air pollution control processes, addition to ash quench slurry	Applicable controls (e.g., resource recovery disposal in lined pond, dissolved solids removal, etc. are waste- and site-specific; cost and performance data should be developed on a case-by-case basis.
Acid wastewater	Product separation and purification	Dissolved organics, thiocyanate, trace elements	Oxidation, use as cooling-tower or quench water makeup	—
Leachates	Gasifier ash, boiler ash, FGD sludge, biosludge, spent catalysts	Trace elements, organics	Landfill should have impervious clay liner and a leachate collection system. If buried in the mine, the mine should be dry and of impervious rock or clay.	—
Treated aqueous wastes	Wastewater treatment	Dissolved and suspended solids, trace elements	Forced or natural evaporation	The effectiveness and costs of various applicable controls (e.g., solar or forced evaporation, physical-chemical treatment for water reuse, etc.) not determined.

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Table 10A-3.—Solid Waste Stream Sources, Components, and Controls (indirect liquefaction)

Solid waste stream	Source	Stream components of major concern	Controls	Comments
Ash or slag	Gasification	Trace elements, sulfides, thiocyanate, ammonia, organics, phenols, cyanides, minerals	Combined with boiler ash and flue gas desulfurization sludge and disposed of in a lined landfill or pond, or buried in the mine	Ash is more than 90 percent of the solid wastes generated at a Lurgi plant. The choice and design of disposal system depend on the ash content of coal and plant/mine site characteristics.
Scrubber sludge	Power/steam generation	Calcium sulfate, calcium sulfite, trace metals, limestone, alkali metal carbonates/sulfates	Disposed of with the gasifier ash	—
Boiler ash	Power/steam generation	Trace elements, minerals	Disposed of with the gasifier ash	—
Sludge	Waste treatment	Trace elements, polycyclic aromatic hydrocarbons	Combined with gasifier ash, boiler ash and flue gas desulfurization sludge and disposed of in a lined landfill or buried in the mine. May also be incinerated	Because of lack of data on waste quantities and characteristics, optimum control(s) cannot be established.
Spent catalysts	Gas shift conversion, catalytic synthesis, sulfur recovery (gaseous emission control)	Metallic compounds, organics, sulfur compounds	Process for material recovery, or fixation/ encapsulation and disposal in landill or mine	The technical and economic feasibility of resource recovery have not been established
Tarry and oily sludges	Product/byproduct separation	Mono- and polycyclic aromatic hydrocarbons, trace elements	Injection into the gasifier, disposal in a secure landfill, return to the mine for burial, incineration	Because of lack of data on waste quantities and characteristics, optimum control(s) cannot be established

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Table 10A-4.—Gaseous Streams, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Air emissions discharged	Components of concern	Control methods
Coal storage and pretreatment	Coal dust	Respirable dust, particulates, trace elements	Spray storage piles with water or polymer. Cyclones and baghouse filters for control of dust due to coal sizing.
	Particulate-laden flue gas from coal dryers	Respirable dust, particulates trace metals, sulfur and nitrogen oxides	Cyclones and baghouse filters. Wet scrubbers such as venturi.
Liquefaction	Preheater flue gas	Particulate, sulfur and nitrogen oxides	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Pressure letdown releases	Hydrocarbons, hydrogen sulfide, hydrogen cyanide, ammonia, PAH, hydrogen, phenols, cresylics	Flaring[a]
Separation:			
Gas separation	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Solids/liquids separation	Preheater flue gas	Same as the liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate-laden vapors from residue cooling (SRC-II)	Particulate, hydrocarbons, trace elements	Cyclone and baghouse filter. Wet scrubbers.
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Purification and upgrading:			
Fractionation	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate-laden vapors from product cooling (SRC-I)	Same as for SRC-II residue cooling	Cyclone and baghouse filter. Wet scrubbers
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Hydrotreating	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen and particulate components.
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Water cooling	Drift and evaporation	Ammonia, sodium, calcium sulfides/sulfates, chlorine, phenols, fluorine, trace elements, water treatment chemicals	No controls available—good design of water management system can minimize losses.
Steam and power generation	Boiler flue gas	Sulfur and nitrogen oxides, particulates	Sulfur dioxide scrubbing, combustion modifications.
Hydrogen generation	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
Acid gas removal	Pressure letdown releases	Hydrogen sulfide, hydrogen cyanide, carbon oxides, light hydrocarbons	Flaring[a]
Sulfur recovery	Flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Low-sulfur effluent gas[b]	Hydrogen sulfide, hydrogen cyanide, sulfur dioxide	Carbon absorption. Direct-flame incineration. Secondary sulfur recovery (Beavon).
Hydrogen/hydrocarbon recovery	Pressure letdown releases	Hydrogen, hydrocarbons	Direct-fired afterburner
Product/byproduct storage	SRC dust (SRC-I)	Respirable dust, particulates	Spray storage piles with water.
	Sulfur dust	Elemental sulfur	Store in enclosed area.
	Hydrocarbon vapors	Phenols, cresylics, hydrocarbons, PAH	Spills/leaks prevention.

[a] Collection, recovery of useful products and incineration may be more appropriate.

[b] A secondary sulfur recovery process may be necessary to meet specified air emission standards.

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Table 10A-5.—Liquid Stream Sources, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Wake effluents discharged	Components of concern	Control methods
Coal pretreatment	Coal pile runoff	Particulates, trace metals	Route to sedimentation pond.
	Thickener underflow	Same as above	Route to sedimentation pond.
Water cooling	Cooling tower blowdown	Dissolved and suspended solids	Sidestream treatment (electrodialysis, ion exchange or reverse osmosis) permits discharge to receiving waters.
Hydrogen generation	Process wastewater	Sour and foul wastewater; spent amine scrubbing solution	Route to wastewater treatment facility.
Acid gas removal	Process wastewater	Dissolved hydrogen sulfides, hydrogen cyanide, phenols, cresylics	Route to wastewater treatment facility.
Ammonia recovery	Process wastewater	Dissolved ammonia	Route to wastewater treatment facility.
Phenol recovery	Process wastewater	Dissolved phenols, cresylics	Route to wastewater treatment facility.

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Table 10A-6.—Solid Waste Sources, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Solid waste discharged	Components of concern	Control methods
Coal pretreatment	Refuse	Mineral matter, trace elements	Landfill, minefill
Solids/liquids separation	Excess residue (SRC-II) or filter cake (SRC-I)	Mineral matter, trace elements, absorbed heavy hydrocarbons	Gasification to recover energy content followed by disposal (landfill or minefill
Hydrotreating	Spent catalyst	Metallic compounds, absorbed heavy organics, sulfur compounds	Return to manufacturer for regeneration
Steam and power generation	Ash	Trace elements, mineral matter	Landfill, minefill
Hydrogen generation	Ash or slag	Trace elements, sulfides, ammonia, organics, phenols, mineral matter	Landfill, minefill

SOURCE: U.S. Department of Energy, *Energy Technologies and the Environment, Environmental Information Handbook*, DOE/EV/74010-1, December 1980.

Chapter 11

Water Availability for Synthetic Fuels Development

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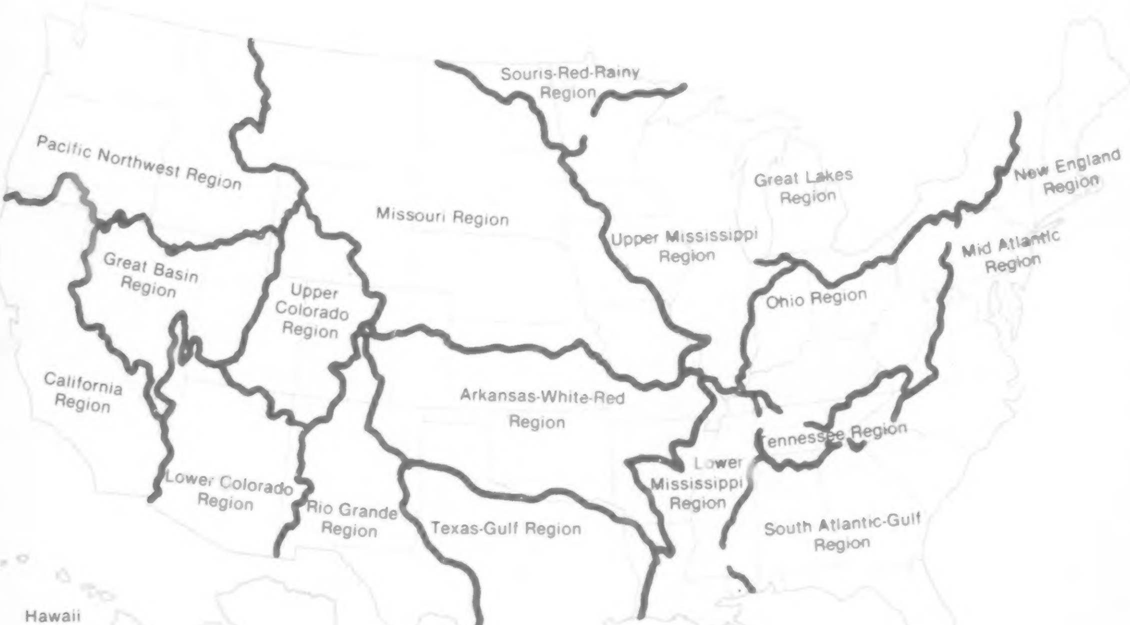
Chapter 11

Water Availability for Synthetic Fuels Development

INTRODUCTION

Operation of a synthetic fuels plant requires a steady supply of water throughout the year for both plant and site activities. Availability of water will be determined not only by hydrology and physical development potential, but also by institutional, legal, political, and economic factors which govern and/or constrain water allocations and use among all sectors. This chapter expands the environmental discussion of the role of water in synfuels development and examines the major issues that will determine both water availability for synfuels and the impacts of procuring water supplies for synfuels on other water users. There are five river basin areas where oil shale and coal resources are principally located: in the eastern basins of the Ohio, Tennessee and the Upper Mississippi, and in the western basins of the Upper Colorado and the Missouri (see fig. 24).

Figure 24.—Water Resources Regions


Souris-Red-Rainy Region
Pacific Northwest Region
Missouri Region
Great Lakes Region
New England Region
Upper Mississippi Region
Mid Atlantic Region
Great Basin Region
Upper Colorado Region
Ohio Region
California Region
Arkansas-White-Red Region
Tennessee Region
Lower Mississippi Region
Lower Colorado Region
Rio Grande Region
Texas-Gulf Region
South Atlantic-Gulf Region
Hawaii Region
Alaska Region
Caribbean Region

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources 1975-2000*, vol. 2, pt. I, p. 3.

WATER REQUIREMENTS FOR SYNFUELS PLANTS

Estimates of the consumptive use requirements of generic synthetic fuels plants producing 50,000 barrels per day oil equivalent (B/DOE) of product are shown in table 80. In general, the actual amount of water consumed will vary according to the nature of the products produced, process methods, plant design, and site conditions. In coal conversion, the largest single component of total water consumption is typically for cooling,* with other major components being for hydrogen production, waste disposal, and revegetation. In producing synfuels from oil shale, retorting and upgrading require the most water; other major uses are for the handling and disposal of spent shale, and for revegetation.

Table 80.—Estimates of Net Consumptive Use Requirements of Generic Synfuels Plants (50,000 B/DOE)[a]

	Acre-feet/year	Barrels water/ barrel product
Gasification	4,500-8,000	1.9-3.4
Liquefaction	5,500-12,000	2.3-5.1
Oil shale	5,000-1[illegible]	2.1-5.1

[a] Available estimates are based on theoretical calculations, conceptual designs, small-scale experimental facilities, etc. A range is shown for each generic process in order to reflect differences among process technologies (e.g., indirect liquefaction will generally consume more water than direct liquefaction; modified-in-situ will generally consume less water than aboveground oil shale processes), plant design options (e.g., alternative methods of water reuse, conservation, and cooling), and sites. Estimates also vary with the level of detail and state of development of the engineering designs. There are also at least two major elements of uncertainty surrounding these estimates. First, both the refinement and optimization of operational requirements are limited by the lack of commercial experience. Secondly, estimates commonly assume zero wastewater discharge, which is to be achieved via the treatment and reuse of plant wastewater for cooling water makeup and boiler feed; however, the treatment processes to be used generally have yet to be demonstrated on a commercial scale. Although the estimates shown in table 80 may thus not be representative of actual consumptive use requirements in specific cases, the magnitude of the other uncertainties concerning water availability in general, as discussed in this chapter, will likely overshadow the question of how much water will be required for expected synfuels development. The following references provide additional details:

1. Office of Technology Assessment, *An Assessment of Oil Shale Technologies*, June 1980, ch. 9.
2. Ronald F. Probstein and Harris Gold, *Water in Synthetic Fuel Production*, MIT Press, Cambridge, Mass., 1978.
3. R. M. Wham, et al., *Liquefaction Technology Assessment—Phase 1: Indirect Liquefaction of Coal to Methanol and Gasoline Using Available Technology*, Oak Ridge National Laboratory, Oak Ridge, Tenn., February 1981.
4. Exxon Research and Engineering Co., *EDS Coal Liquefaction Process Development*, phase V, vols. I, II, and III, March 1981.
5. Harris Gold and David J. Goldstein, "Water Requirements for Synthetic Fuel Plants;" and Harris Gold, J. A. Nardella, and C. A. Vogel (eds.), "Fuel Conversion and Its Environmental Effects," *Chemical Engineering Progress*, August 1979, pp. 58-64.

SOURCE: Office of Technology Assessment.

Synfuels plants will also generally require water for other process-related activities such as environmental control (e.g., dust control) and for associated growth in population, commerce, and industry (e.g., for water supply and sewerage). Plant activities will not all require water of similar qualities. As examples, high-quality water is required for processing; intermediate-quality water is required for cooling; mining, materials preparation, and disposal activities are the least sensitive to water quality characteristics.

Procuring water supplies for synfuels plants will represent a small fraction of total plant investment and operations costs (typically less than 1 percent).** Thus, assuming that the overall economic feasibility of the plant has been established, the more critical industrial considerations in selecting a water source will be the ease of acquiring water of appropriate quality and the certainty of the yield. Major water sources for synfuels would include the direct diversion of surface water, the purchase or transferring of existing water rights, the use of existing or the construction of new storage, the use of tributary and nontributary ground water,*** savings from improved efficiency, reuse, and conservation by all users, and interbasin diversions.

The feasibility and attractiveness of sources will vary among sites according to environmental, social, legal, political, and economic criteria, and it is therefore difficult a priori to predict how and which water "packages" will be assembled. Evidence suggests that the industry is conservative in planning for a plant's water resource needs in order to ensure (both hydrologically and legally) that the plant obtains its minimum operating requirements. As examples, developers can secure several different sources of supplies; estimates of resource needs will include a margin of safety; and sources can be "guaranteed" by obtaining agreements not only with rights holders but also with upstream appropriators and/or potential downstream claimants. Synfuels technology modifications should also be forthcoming from the industry, if needed to reduce water needs.

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*The amount of water consumed in cooling will depend on many factors, including the degree to which evaporative or "wet" cooling, or dry cooling, are used. Air or "dry" cooling is an alternative to wet cooling but is less efficient and generally more expensive.

**Obtaining reliable and comparable cost data on the procurement of water to the synfuels industry is difficult because of variation in the conditions surrounding each sale (e.g. water rights vary according to their seniority, historic use, point of diversion, etc.). As examples, annual costs per acre-foot of consumption vary between $50 to $300; water rights have sold for as high as $2,000/acre-foot (in perpetuity). Assuming a cost of $2,000/acre-foot, water rights costs would still represent a maximum of only 0.8 percent of the cost of a $2 billion plant with an average annual consumption of 8,000 acre-feet. Note that what is bought is the right to use water, not the water per se.

Costs are, nevertheless, important industrial criteria for evaluating alternative sources of water supply. Costs will also be important for water resources planning efforts, as they will help to determine the nature and extent of impacts on other water users from synfuels development.

***The development of deep, nontributary ground water, which is hydrologically unconnected to the surface flow, can be considered as an "additional" source of water. Development of tributary ground water, which is hydrologically connected to streamflow, does not represent an increase in supply and may alter the surface flow regime.

IMPACTS OF SYNFUELS DEVELOPMENT ON WATER AVAILABILITY

In the aggregate, water consumption requirements for synfuels development are small. Achieving a synfuels production capability of 2 MMB/DOE would require on the order of 0.3 million acre-feet/year (AFY), which will be distributed among all of the Nation's major oil shale and coal regions. This compares with an estimated (1975) total national freshwater consumptive use of 119 million AFY, of which about 83 percent is for agriculture.[1] Table 81 shows the general hydrologic characteristics of the principal river basins to be affected.

Although in the aggregate synfuels water requirements are small, each synfuels plant, nevertheless, is individually a relatively large water consumer. Depending on both the water supply sources chosen for a synfuels plant and the size and timing of water demands from other users, synfuels development could create conflicts among users for an increasingly scarce water supply or exacerbate conflicts in areas where water is already limited or fully allocated. Sectors that will be competing for water will vary among the regions and will include both offstream uses (e.g., agriculture, industry, municipalities) and instream uses (e.g., navigation, recreation, water quality control, fish and wildlife, hydropower). Because energy developers can afford to pay a relatively high price for water, nonenergy sectors are not likely to be able to compete economically against synfuels for water. However, it is speculative to identify which sectors may be the most vulnerable to synfuels development.

Public reactions to proposed water use change and nonmarket mechanisms can be used to allocate and protect water for use by certain sectors depending on the region and State. Examples of nonmarket mechanisms include the assertion of Federal reserved water rights, water quality legislation, and State water allocation laws. While such mechanisms may prevent developers from always obtaining all the water they need, the synfuels industry is expected to obtain the major portion of its water requirements.

Table 81.—Regional Streamflow Characteristics 1975[a] (millions acre-feet/year)

	Mean annual streamflow[b]	Consumption[c]		Low flow ratio[d]	Low flow month
		1975	2000		
Ohio	199	2.0	4.9	0.15	September
Tennessee	46	0.5	1.2	0.38	September
Upper Mississippi	136	1.3	3.0	0.23	January
Upper Colorado	11	2.7	3.6	0.12	July
Missouri	49	17.3	22.3	0.19	January

[a] U.S. Water Resources Council (WRC), *The Nation's Water Resources—1975-2000.*
[b] WRC, table IV-1. Note that all these outflows are inflows to a downstream river basin.
[c] WRC, table III-3.
[d] Ratio of the annual flow of a very dry year (that flow which will be exceeded with a 95-percent probability in any year) to the mean annual flow. WRC, table IV-2.

SOURCE: U.S. Water Resources Council as tabulated by OTA.

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[1] U.S. Water Resources Council, *The Nation's Water Resources—1975-2000,* December 1978. The assessment projects a total national freshwater consumption of 151 million AFY in 2000, of which about 70 percent would be for agriculture.

Photo credit: Office of Technology Assessment

Competing uses will increase pressures on the Nation's water resources, especially in the arid West

The nature and extent of the impacts of synfuels development on water availability in general, and on competing water users, are controversial. The controversy arises in large part because of the many hydrologic, institutional, legal, and political contraints and uncertainties that will ultimately determine when, how, and if users will be able to obtain the water they need. Furthermore, analyzing these constraints and uncertainties is difficult because of many additional complex factors: the lack of dependable and consistent data, limitations of demand-forecasting methods, time and budget constraints, and the unpredictability of future administrative decisions and legal interpretations. In some cases, the uncertainties about water availability in general appear to be so large that they overshadow the question of how much water will be required for synfuels development.

OTA's study[2] found that there was considerable variation in the quality, detail, and scope of the water availability assessments that have been completed related to synfuels development. Few studies take into account all of the issues that will determine resource allocations and use; and studies rarely try to address the likely, cumulative water resource impacts of alternative decisions on reducing uncertainties and resolving conflict among competing water users. Decisionmakers need to be better informed about the assumptions and uncertainties upon which reports are predicated, so that estimates can be properly interpreted and tradeoffs can be evaluated.

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[2] Wright Water Engineers, Inc., "Water Availability for Synthetic Fuels," prepared for the Office of Technology Assessment, June 1981.

Some of the major uncertainties about water availability for synfuels are discussed below. More informed decisions on water availability questions, however, can only partially be achieved by "improving" studies themselves; more informed decisions also depend on greatly improved water planning practices in general in the Nation. The present fragmentation of responsibilities for water policy, planning, and management effectively prevents an assessment of the cumulative impacts of water resource use on an ongoing and comprehensive basis.*

WATER AVAILABILITY AT THE REGIONAL LEVEL

Eastern River Basins

In the principal eastern basins where energy resources are located (i.e. Ohio, Tennessee, and the Upper Mississippi), water should be adequate on the mainstems and larger tributaries, without new storage, to support planned synfuel development.[3] However, localized water scarcity problems could arise during abnormally dry periods or due to conflicts in use on smaller tributaries. The severity and extent of local problems cannot be fully ascertained from existing data and have not yet been examined comprehensively,* but, with appropriate water planning and management, these problems should be reduced if not eliminated.

There are, nevertheless, various uncertainties in the eastern basins that will influence water availability for synfuels development, and difficult local situations could arise.[4] For example, 7-day, 10-year minimum low flows are used to estimate water availability.** These estimates are essentially based on recorded streamflow data which can be of varying quality. Furthermore, by using historical streamflow records directly, reports on water availability in the eastern basins characteristically underestimate the frequency of future critical low flows; i.e., as flow depletions increase in the future, the critical flow associated with the 7-day, 10-year frequency will actually occur more often in the future than the historical data would indicate.

The political, institutional, and legal factors that will determine water availability for synfuels in the eastern basins differ in type and complexity from those in the western basins. For example, the East and West have different regional hydrologic characteristics, with the East being relatively humid. There are also varying legal and administrative structures as shown in figures 25 and 26: riparian water law is generally applied in the East whereby riparian landowners are entitled to an equal, "reasonable" use of adjacent streamflow; the prior appropriation doctrine is generally applied in the West whereby water rights are based on "beneficial" use with priorities assigned according to "first in time, first in right." Furthermore, in the East there is a general lack of treaties and compacts, and there are no major Federal (including Indian) reserved water rights questions.

Although water may thus appear to be more readily available for synfuels development in the East (e.g., through the transfer of ownership of riparian land), eastern water law can result in significant uncertainty concerning the dependability of the supply: because all users have equal

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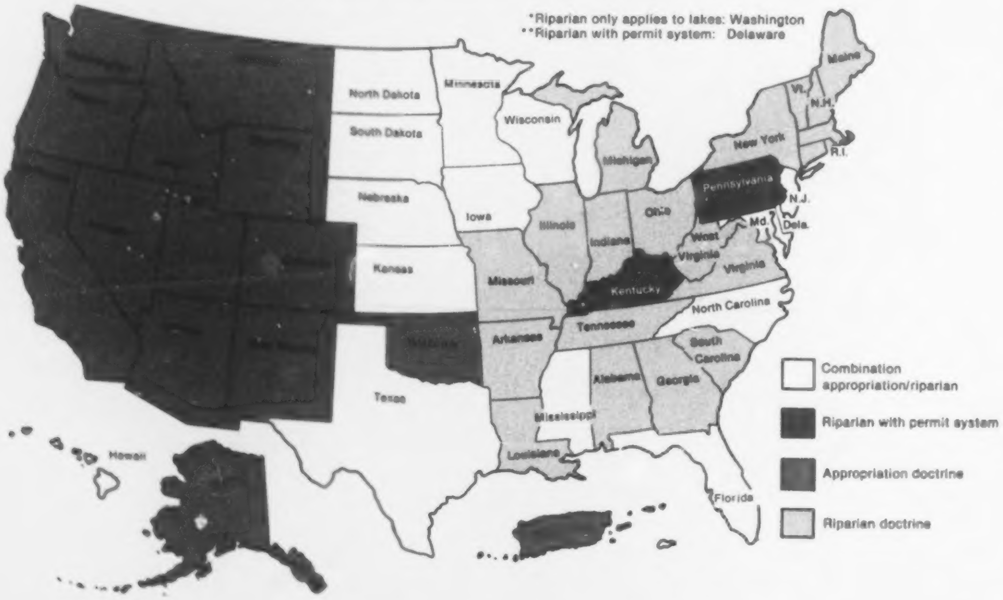
*The fragmentation of water-related responsibilities among agencies, States, and levels of governments arises in large part because river system boundaries rarely coincide with political boundaries. As a result, there can be major inconsistencies in water management practices across the country (e.g., inconsistent criteria for evaluation; the lack of integrated planning—including data management—for ground and surface waters, water quality and quantity, and instream and offstream uses).

[3] Ibid.

*For example, available reports related to synfuels for the Tennessee River Basin generally deal with specific project sites; the sparsity of comprehensive information with respect to cumulative impacts and possible water use conflicts is presumably because of the large quantities of water available at the regional level. The Ohio River Basin Commission study focuses on water availability for plants located on the mainstem, even though there are facilities being proposed for tributaries.

**The use of the 7-day, 10-year minimum flow in the East is also the basis for water quality regulations and for estimating critical conditions for navigation in rivers with limited storage.

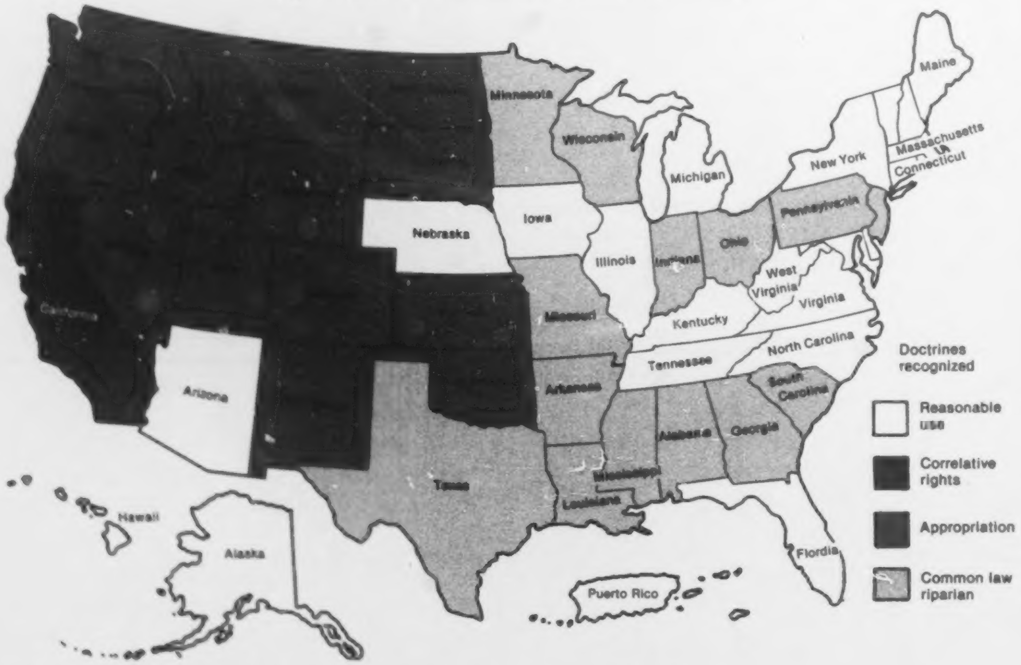
Figure 25.—The Nation's Surface Water Laws


North Dakota
South Dakota
Nebraska
Kansas
Texas
Minnesota
Iowa
Wisconsin
Missouri
Arkansas
Illinois
Indiana
Michigan
Ohio
Pennsylvania
New York
Maine
Vt.
N.H.
R.I.
N.J.
Md.
Dela.
West Virginia
Virginia
Kentucky
Tennessee
North Carolina
South Carolina
Georgia
Alabama
Mississippi
Louisiana
Florida
Hawaii
Combination appropriation/riparian
Riparian with permit system
Appropriation doctrine
Riparian doctrine

*Riparian only applies to lakes: Washington
**Riparian with permit system: Delaware

SOURCE: U.S. Water Resources Council, (*The Nation's Water Resources 1975-2000*, vol. 2, pt. iv, p. 118).

Figure 26.—The Nation's Ground Water Laws


Minnesota
Wisconsin
Michigan
Iowa
Nebraska
Illinois
Indiana
Ohio
Pennsylvania
New York
Maine
Massachusetts
Connecticut
West Virginia
Virginia
Kentucky
Tennessee
North Carolina
South Carolina
Georgia
Alabama
Mississippi
Louisiana
Arkansas
Missouri
Texas
California
Arizona
Florida
Hawaii
Alaska
Puerto Rico
Doctrines recognized
Reasonable use
Correlative rights
Appropriation
Common law riparian

SOURCE: U.S. Water Resources Council, (*The Nation's Water Resources 1975-2000*, vol. 2, pt. iv, p. 118).

BEST AVAILABLE COPY

rights under riparian law, the law does not protect given users against upstream diversions or against pumping by adjacent wells.* Uncertainty also arises because eastern water law has not been as well advanced through court tests as in the West. There are also questions in the East concerning the availability of water from Federal storage (i.e., in the Ohio River Basin) because of uncertainties regarding who has responsibility for marketing and reservoir operation.

The Western River Basins

Competition for water in the West already exists and is expected to intensify with or without synfuels development. There are potential sources of supply in both the Upper Colorado and the Missouri River basins that could support synfuels development. However, the issues determining whether and the extent to which these sources will be available for use differ between the two basins. These issues concern complex State water allocation laws, compacts and treaties, Federal including Indian reserved water rights claims, and the use of Federal storage. In addition, the use of "mean annual virgin flows" in both regions to characterize the hydrology results in the masking of important elements of hydrologic uncertainty.** However, and in contrast with the situation in the East, although the complex water setting in the West will probably make obtaining water difficult, the user will be more assured of a certain supply once a right is obtained.[5]

Missouri River Basin

The magnitude of the institutional, legal, political, and economic uncertainties in the Missouri River Basin, together with the need for major new water storage projects to average-out seasonal and yearly streamflow variations, preclude an unqualified conclusion as to the availability of surface water resources for synfuels development.[6] Ground water resources are not well understood in the basin, but are not likely to be a primary source of water for synfuels.

Major coal deposits for synfuels development in the Missouri River Basin lie within and adjacent to the Yellowstone River subbasin. The availability of water for synfuels from the Yellowstone subbasin, however, could be constrained by the provisions of interstate compacts, i.e., the Yellowstone River Compact. For example, at present all signatory States must approve any water exports from the basin (e.g., to the coal-rich Belle Fourche/Gillette area where water is scarce). Although export approval procedures are now being challenged in court and States have begun to modify approval procedures, such approvals are likely to take some time. Furthermore, additional storage would likely be required to develop fully the compact allocations.

Federal reserved water rights are often senior rights and have the potential of preempting current and future uses. These rights, however, have yet to be quantified and are a major source of uncertainty for water planning. The largest single component of Federal reserved rights are Indian water rights. There is a general lack of quantitative data concerning Indian water rights because of political controversy over which jurisdictions should be adjudicating the claims, varying interpretations of the purposes for which water rights reservations can be applied, and ongoing litigation.[7]

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*For example, Federal storage has not yet been utilized in Illinois because delivery of the water from the reservoirs (e.g., to the synfuels plants) cannot be guaranteed along the river; riparian landowners along the way could intercept the released water. Energy companies are thus faced with having to build private pipelines.

**The accuracy of mean annual virgin flows is uncertain due to possible inaccuracies in the underlying data both on streamflows and on depletions. (Depletions are usually not measured directly for practical reasons.) Furthermore, virgin flow estimates are treated as both deterministic and stationary, rather than as time-varying, which prevents the variability of streamflows from being addressed accurately in areas lacking sufficient storage. Estimates of the mean annual virgin flow for the Colorado River at Lees Ferry vary from 12.5 million to 15.2 million acre-feet depending on the assumptions (in this case, the period of the historical record) used.

In general, the use of aggregated data, in the form of regional and basinwide averages, will mask the local and cumulative downstream effects of development on water availability. Such data do not provide information about either the seasonal variability of streamflows and demands or the relative positioning and hence interrelationships among users. These factors are important for identifying potential competition for water, especially in areas where water is scarce and subject to development pressures, as will often characterize locations for synfuels development.

[5] Ibid.

[6] Ibid.

[7] The only "official" Government estimates of Indian reserved water rights project depletions (i.e. requirements) of 1.9 million acre-

(continued on next page)

Other major uncertainties that could effect the availability of water for synfuels concern State water allocation laws. For example, Montana has established instream flow reservations in the lower-Yellowstone River of 5.5 million AFY to protect future water quality and wildlife. Over 500,000 AFY have also been reserved in the basin for future municipal and irrigation use. Additional storage would be required to meet these reservations during years of low flow, but Montana State officials generally do not advocate the construction of new mainstem storage, even if instream flow shortages were to occur otherwise, as this would interfere with the free-flowing nature of the river.[8] [9] No determination has yet been made as to how these instream flow reservations would be accommodated under the Yellowstone Compact.

The transferring of water rights from existing (e.g., agricultural) to new (e.g., synfuels) uses in Montana is subject to administrative restrictions under primarily the 1973 Water Use Act, and State environmental and facility siting acts.[10] Because of these restrictions, water rights are not freely transferable from existing users, and, in effect, there is presently no economic market for rights transfers.

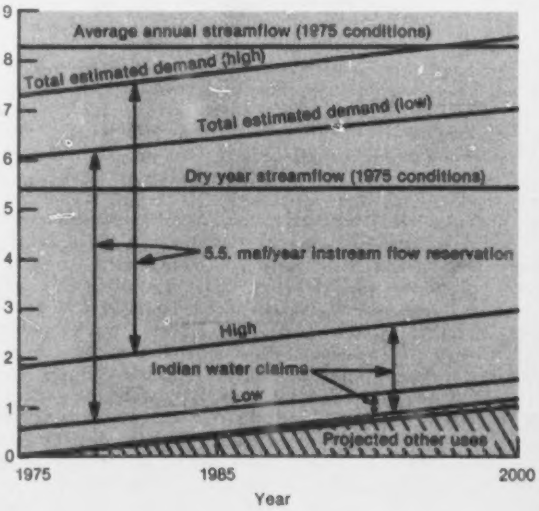
State water laws and statutory provisions in other Upper Basin States similarly could constrain water rights transfers to synfuels.[11] As examples, water for irrigation takes precedence in these States over water for energy development, and the "public interest" is to be explicitly considered in approving water allocations. Alternatively, other laws could work to the disadvantage of nonenergy sectors, such as navigation in the Missouri region under the Federal Flood Control Act of 1944 (33 USC 701-(b)).

Many of the water availability issues in the Missouri River Basin cannot be adequately evaluated because of a lack of supporting data and case law interpretations. Figure 27 illustrates the possible magnitude of uncertainty by superimposing the major projected consumptive uses (excluding synfuels) onto the availability of water in the Yellowstone River. As can be seen, assuming a low total estimated demand growth scenario, demands would not be met in a dry year without additional storage. Assuming a high-growth scenario, not only would demands not be met in a dry year without storage, but they would also exceed the average annual flow with additional storage.

Upper Colorado River Basin

Although water may not be available in certain tributaries and at specific sites, sources of water

Figure 27.—Streamflows and Projected Increased Incremental Water Depletions, Yellowstone River at Sidney, Mont.



SOURCE: "Water Availability for Synthetic Fuels," Wright Water Engineers, Inc., contractor report to OTA, June 5, 1981.

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feet for the year 2020 in the Yellowstone. (U.S. Department of Interior, Water for Energy Management Team, *Report on Water for Energy in the Northern Great Plains With Emphasis on the Yellowstone River Basin,* January 1975.) A lower estimated value of 0.5 million acre-feet appeared in a 1960 background paper (for a larger framework study of the Missouri River Basin) by the Bureau of Reclamation. For a detailed discussion of Indian reserved water rights, the reader is referred to Constance M. Boris and John V. Krutilla, *Water Rights and Energy Development in the Yellowstone River Basin,* Resources for the Future, 1980.

[8] Wright Water Engineers, Inc., op. cit.

[9] Personal communications, Department of Natural Resources and Conservation, State of Montana.

[10] For a detailed discussion of State water allocation laws see Grant Gould, *State Water Law in the West: Implications for Energy Development,* Los Alamos Scientific Laboratory, Los Alamos, N. Mex., January 1979.

[11] Ibid.

generally exist in the Upper Colorado River Basin that could be made available to support OTA's low and high estimates of oil shale development through at least 1990.* However, the institutional, political, and legal uncertainties in the basin make it difficult to determine which sources would be used, the actual amount of water that would in fact be made available from any source to support synfuels development, and thus the water resource impacts of using any source for synfuels on other water users. Until major components of these uncertainties are analyzed quantitatively and start to become resolved, the extent to which synfuels production can be expanded beyond a level of several hundred thousand barrels/day (i.e., about 125,000 AFY) cannot be estimated with confidence.[12]

One potential source of water supply for synfuels is storage from Federal reservoirs. For example, approximately 100,000 AFY could be made available for synfuels from two Federal reservoirs on the western slope of Colorado (Ruedi and Green Mountain). However, the amount of water available is uncertain because of questions regarding firm yields, contract terms for water sales, which purposes are to be served by the reservoirs, competing demands, the marketing agent, and operating policy.

Under State water laws, water rights throughout the basin—in Colorado, Utah, and Wyoming—can generally be transferred (e.g., from agriculture) via the marketplace (i.e., sold) to synfuels developers who can afford to pay a relatively high price for water.[13] The degree to which developers rely on such transfers will determine the subsequent economic and social impacts on the users being displaced and, in turn, on the region.* The transfer process, however, is time-consuming and legally cumbersome, is constrained under State water law by the nature of the original right, and is subject to political and legal challenge.

Some provisions of the laws and compacts governing water availability to the States within the basin will not be tested and interpreted until water rights in the basin are fully developed. For example, procedures and priorities have not yet been developed for limiting diversions among the Upper Basin States when downstream commitments to the Lower Basin, under the Colorado River Basin Compact, cannot otherwise be met. There is also controversy about whether the Upper Basin States as a whole will be responsible for providing any of the 1.5 million AFY commitment to Mexico under the Mexican Water Treaty of 1944-45. Individual States within the basin, such as Colorado, have generally not yet developed procedures and priorities for internally administering their downstream delivery commitments for when the basin becomes fully developed; thus, the impacts of a State's allocation of available water to individual subbasins and users within that State, such as synfuels, cannot yet be determined. State water law also generally evolves through individual court cases, so that the cumulative effects of development are not known.

There are generally no institutional or financial mechanisms for obtaining water for synfuels, either through conservation or through increased efficiency in water use in other sectors, as in other parts of the country. In Colorado, for example, changes in agricultural practices to increase water efficiency are likely to be challenged legally, since downstream water rights appropriators are entitled to return flows resulting from existing albeit inefficient practices. It has been reported that basin exports for municipal uses could be reduced by as much as 200,000 to 300,000 AFY with improved water use efficiency.[14]

Other uncertainties that affect water availability for synfuels in the area include: Federal reserved water rights (e.g., for the Naval Oil Shale Reserve at Anvil Points, Colo.) have not yet been quantified; storage would have to be provided in the White River Basin (where the Uinta and Piceance Creek oil shale reserves are located) but prime reservoir sites are located in designated wilderness areas; there is as yet no compact between Colorado and Utah apportioning the flows of the White River; and in Colorado, in order to develop much of the deep ground water in the Piceance Basin, oil shale developers must prove that the ground water is nontributary, for which data are often lacking and difficult to obtain. The resolution of the uncertainties in the Upper Colorado could limit large-scale synfuels growth as illustrated in table 82, but "even at these highly aggregated levels for the entire Upper Colorado River Basin, the confidence limits or ranges that are placed on estimates of water availability are so broad that they tend to (overshadow) the amount of water needed for synfuels development."[15]

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*The low estimate for shale oil production in 1990 (see ch. 6) implies a range of annual water use of 20,000 to 48,000 acre-feet; the high estimate implies a range of 40,000 to 96,000 acre-feet. By 2000, annual water requirements would be, respectively, 50,000 to 120,000 acre-feet, and 90,000 to 216,000 acre-feet.

[12] Wright Water Engineers, Inc., op. cit.

[13] Gould, op. cit.

*Irrigation requirements are determined by many factors, including climate, crop, irrigation methods, etc. Assuming that agriculture consumes 1.5 to 2.5 acre-feet/acre in the Rocky Mountain area, an average oil shale plant consuming 8,500 AFY would need to acquire water rights applicable to about 3,400 to 5,700 irrigated areas.

[14] Office of the Executive Director, Colorado Department of Natural Resources, *The Availability of Water for Oil Shale and Coal Gasification Development in the Upper Colorado River Basin,* Upper Colorado River Basin 13(a) Assessment, October 1979.

Table 82.—Preliminary Quantification of Uncertainties With Respect to Water Availability in the Upper Colorado River Basin

Annual amount available for consumption (millions of acre-feet)[a]		
	12.5 - 15.2	Estimates of mean annual flow of the Colorado River at Lees Ferry
Subtract	7.5	Required delivery to the Lower Basin
	5.0 - 7.7	
Subtract	0.75	Estimate of the Upper Basin's Mexican Treaty obligation
	4.25 - 6.95	
Subtract	.65	Estimated annual reservoir evaporation from Flaming Gorge, Lake Powell, and the Curecanti Unit Reservoirs
Total	3.50 - 6.30	
Annual projected consumptive demands (millions of acre-feet) in 2000[b]		
Total	4.10 - 4.78	(excluding synfuels)
Total	4.15 - 4.90	(including OTA low estimates for oil shale[c])
Total	4.19 - 5.00	(including OTA high estimates for oil shale[c])

[a] Does not make allowances for the quantification of Federal reserved water rights claims (the Naval Oil Shale Reserve at Anvil Points has claimed, for example, 200,000 AFY), the effect of potential environmental constraints (e.g., salinity control, protection of endangered species), or the availability of Federal storage.

[b] Estimates are for 2000 and exclude synfuels development (Colorado Department of Natural Resources, Section 13(a) Assessment of the Upper Colorado River Basin; 1975 estimate = 3.12 maf). Instream uses are not included.

[c] The low estimate for shale oil production in 1990 (see ch. 6) implies a range of annual water use of 20,000 to 48,000 acre-feet; the high estimate implies a range of 40,000 to 96,000 acre-feet. By 2000, annual water requirements would be, respectively, 50,000 to 120,000 acre-feet, and 90,000 to 216,000 acre-feet.

SOURCE: OTA based on Wright Water Engineers, Inc.

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[15] Wright Water Engineers, Inc., op. cit., p. IV-38.

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The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts which can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

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